

**NASA TECHNICAL
MEMORANDUM**

NASA TM X-62,322

NASA TM X-62,322

(NASA-TM-X-62322) TRENDS IN TRANSPORT
AIRCRAFT AVIONICS (NASA) 83 p HC

CSCL 01C

N74-12715

**G3/02 Unclass
24206**

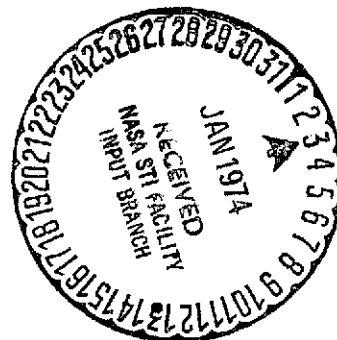
TRENDS IN TRANSPORT AIRCRAFT AVIONICS

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U.S. Department of Commerce
Springfield, VA. 22151

December 1973



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SUMMARY

This report presents the results of a survey of avionics onboard present commercial transport aircraft. The survey was conducted to identify trends in avionics systems characteristics and to determine the impact of technology advances on equipment weight, cost, reliability, and maintainability.

The report describes transport aircraft avionics systems under the headings of communication, navigation, flight control, and instrumentation. The equipment included in each section is described functionally. However, since more detailed descriptions of the equipment can be found in other sources, the description is limited and emphasis is put on configuration requirements. Since airborne avionics systems must interface with ground facilities, certain ground facilities are described as they relate to the airborne systems, with special emphasis on air traffic control and all-weather landing capability.

INTRODUCTION

The Systems Studies Division conducts broad systems studies of advanced aircraft, including V/STOL and other future transports. These studies include market and economic analysis as well as the analysis of mission requirements and aircraft performance characteristics. A portion of the Division's efforts are devoted to studies in the aeronautical discipline areas to develop improved capability for system analysis. In view of the increasing sophistication of aircraft avionics systems, this study of trends in commercial transport aircraft avionics was conducted to provide direct input to other studies in terms of performance, weight, and cost of advanced avionics.

In order to compare performance, weight, and cost, the avionics equipment must be described in sufficient detail that comparable pieces of equipment can be distinguished; i.e., that degrees of sophistication or complexity can be compared. In this paper, the avionics equipment are briefly defined, then a more specific description and discussion of trends and implications follows. The equipment classifications used are communications, navigation, flight control, instrumentation, and

landing systems. The instrumentation equipment discussed in this paper include air data system, displays, monitoring systems, weather radar, etc. Other instruments onboard the aircraft which may be defined as "system" instruments, and are part of a particular system such as the power plant, are not described in this paper.

The avionics equipment described in this paper includes that in use on transport aircraft including the Concorde, and that likely to be on future U. S. SST and STOL aircraft.

Since avionics systems require precise control of input power, power conditioning equipment is used which also provides isolation between equipments which might otherwise interfere with one another. The power conditioning equipment is considered part of the electric system rather than the avionics system. However, since many avionics-related decisions are based on the electrical system design, the following observations are made. Transport avionics equipment uses mostly d-c power; if a-c is the input to the equipment, it is converted internally. A small fraction of a-c power is used directly to supply synchros and resolvers (ref. 1).

It is the intent of this paper to discuss the equipment which make up the avionics systems of transport aircraft which are currently flying and to use these systems' parameters to identify trends. It is not the intent of this paper to perform a technological forecast but to present information which would be useful for the forecaster.

COMMUNICATIONS SYSTEMS

Communications systems are described by the frequency used, such as VHF, HF, and UHF, or by the function filled, such as Satellite Communications, Transponder, Data Link, VHF Command, Collision Avoidance, and Pilot Warning. The VHF, HF, and UHF systems are used to transmit voice communications and to contact airport towers and Air Traffic Control facilities. HF is used primarily for long distance communications and UHF is used primarily for military communications.

Communications systems which have no voice capability include transponders, Data Link, VHF Command, and others. Transponders are used to identify aircraft in a radar environment; they

transmit a code in response to an interrogation by a ground facility. Data Link and VHF Command, now in the early stages of evaluation, are the transmission of commands or information without voice. Collision avoidance systems and proximity warning indicators are also in the early stages of development and are envisioned to provide not only warning of an impending collision, but also avoidance commands.

VHF Communications

Very High Frequency (VHF) radio communication systems are used to transmit and receive voice communications. They are used primarily to contact airport control towers for takeoff and landing instructions and for enroute reporting. They are capable of communications over line-of-sight distances only; therefore, range for air-to-ground communications is limited by aircraft altitude.

Minimum standard frequencies are provided by a 90-channel receiver (118.0–126.9 MHz with 100 kHz spacing). To be able to communicate on all available VHF frequencies, transport aircraft have 360 transmitting frequencies (118.0–136.0 MHz with 50 kHz spacing) and 560 receiving frequencies (108.00–136.00 MHz with 50 kHz spacing) covering the entire VHF aircraft radio spectrum (ref. 2). Unrestricted IFR operation requires 360-channel communications capability. The FAA anticipates the use of 720 channels (i.e., 25 kHz spacing) will be required at some future date.

A typical VHF transceiver system consists of a transceiver, control panel, shockmount, and antenna. The transceiver, constructed of silicon solid-state devices and microcircuits, is electrically and mechanically divided into frequency synthesizer, transmitter, and receiver circuits. Recent construction techniques have eliminated all tubes. The solid-state transceiver provides an electronically tuned receiver and a broadband transmitter, thus eliminating all mechanical tuning mechanisms and resulting in increased reliability, reduced power drain, and lower user maintenance costs. Capability for 25 kHz channel spacing is available at a cost comparable to previous 50 kHz spaced transceivers. Growth provisions are made for future applications such as SATCOM. VHF navigation and communications transceivers are made for general aviation business and commercial aviation; however, transport aircraft usually have separate communication and navigation transceivers.

HF Communications

High Frequency (HF) radio systems are used to transmit and receive voice communications. They are used primarily for long range communications outside the range of other systems, since this system is not limited to line-of-sight characteristics. HF equipment is carried by transport aircraft flying over oceans or outside the continental United States, not by domestic air carriers unless the same aircraft is flown outside the United States.

An HF system may provide conventional Amplitude Modulation (AM) method of voice communications and/or the more recent Single Sideband (SSB) method. An AM signal is composed of three parts: an RF carrier frequency, upper sideband, and lower sideband. All of the voice information is contained in each sideband so each sideband merely duplicates the information of the other. A SSB signal results when the carrier and one sideband are eliminated.

The SSB method represents a significant improvement in reliability, performance, and maintainability. With SSB, all power amplifier and power supply capacities are utilized in amplifying the intelligence portion of the transmitting signal, resulting in more usable power for transmission. The SSB signal is half the bandwidth of an AM signal. Therefore, a SSB signal requires only half the spectrum space for transmission of information. However, SSB equipment must meet stricter requirements in frequency stability, filter selectivity, and low distortion linear power amplification than does AM. Several types of frequency control are used: serial control, parallel control, or crystal oscillator control (ref. 3).

UHF Communications

Ultra High Frequency (UHF) communications transceivers are used by military aircraft for voice communications at military installations. No UHF communication equipment is provided on civil aircraft.

Selective Calling (SELCAL)

This is a standard provision in ARINC quality VHF communications transceivers which allows an aircraft in flight to be paged by its ground agents. This capability requires that the transceiver have broad band audio output in the receiver. A coded message which is the aircraft's identifier triggers a panel light indicating that the agent on the ground wishes to be contacted by the aircraft crew. The crew must call the ground agent using the VHF communications equipment and ARINC ground stations transmitting on 130.0–132.0 or 132.0–134.0. Not all airlines have the Selcal decoder; Delta, for instance, has its own ground network. The cost of the Selcal decoder is approximately \$1000.

Satellite Communications (SATCOM)

Satellite communications systems are being developed to meet the projected growth in communications during the 1980's. Construction of a U. S. synchronous system has been under consideration for seven years at the Federal Communications Commission (FCC). In May, 1972, a 15-member international consortium led by Lockheed Missiles and Space Company announced the test of high capacity next-generation communications satellites which could be used for aircraft navigation, surveillance and communications (ref. 4).

In anticipation of new airborne communications equipment requirements for satellite communications, ARINC issued ARINC Characteristic 566 in 1968: "Airborne VHF Communications Transceiver and Mark-1 VHF SATCOM System." Boeing 747's have as standard equipment two ARINC 566 satellite communications systems. The proposed intercontinental version of the L-1011-1 would also have two ARINC 566 systems.

ATC Transponder

The Air Traffic Control transponder receives coded signals from a ground station and transmits a coded reply to the ground control station to provide ATC with positive aircraft identification in a radar environment. The system is called the Air Traffic Control Radar Beacon System (ATCRBS).

The ground equipment is an interrogating unit, with the beacon antenna mounted so as to scan with the surveillance antenna of the surveillance radar system. When used in conjunction with an altitude digitizer or a computer, the transponder automatically provides aircraft altitude information to the ground controller on mode C (altitude reporting) if the circuits necessary for automatic altitude reporting have been included in the transponder.

The typical system includes: ATC transponder (2- and/or 3-pulse side-lobe suppression, self-test, visual monitor, altitude encoder); shockmount; control; and L-band antenna (ref. 3).

Data Link/VHF Command

Data Link is a no-voice communications link which allows the transmission of information between an aircraft and the ground in a fraction of the time it would take to relay the information by voice over a radio. This new device is in the test and evaluation stage. Specifications are being developed by the Data Link Subcommittee of the Airline Electronic Engineering Committee (AEEC). The FAA is attempting to determine whether the data link associated with the proposed Discrete Address Beacon System (see CAS/PWI) will eliminate the need for a universal data link that operates in the present VHF air-ground band (referred to as VHF data link or VHF Command). An effort is being made to demonstrate the value to ATC of automatic position reporting via data link, using ground and airborne equipment which appears feasible for implementation by 1975. The equipment being used consists of: INS comparable to the ARINC 561 standard; Airborne VHF communication compatible with ARINC 546 or 566 and ARINC experimental data link equipment; Ground ATC computer processing and situation display equipment (ref. 5). ARINC Report 201 contains the AEEC Data Link Project Newsletters which describe the issues involved in the development of an ARINC specification for data link.

A test system aboard a Pan American Airways B747 in regular scheduled service prints out predeparture and enroute flight clearances on a cockpit monitor. Data is transmitted to the aircraft by VHF at a data bit rate of 2400 per second. Two tones which are frequency coherent to the data bit rate are used to amplitude modulate the radio signal. The electronics are assembled in a standard short 1 ATR box; the printer is located in the cockpit (ref. 6).

Collision Avoidance System (CAS)/Pilot Warning Instrument (PWI)

Collision avoidance systems (CAS) are divided into two groups: *airborne* collision avoidance revolving around the pilot's ability to see and avoid other aircraft; and *ground-based* collision avoidance revolving around the ATC system and the ground controller's ability to use his radar aids. The most promising airborne systems to date are:

Time Frequency System— Developed by McDonnell Douglas, Bendix, Sierra, and Wilcox, measures range, range rate, and altitude of all other similarly equipped aircraft within the nearby airspace (ref. 7). An onboard computer analyzes the data and issues appropriate climb, descend, or turn commands. A synchronized clock baselines the polling of neighboring aircraft in sequence. Various clock synchronization plans have been considered. The system is extremely costly: estimated cost for a single onboard unit is between \$50,000 and \$60,000. Disadvantages are that (1) since it measures the scalars of range and range rate, it cannot distinguish between aircraft on intersecting and parallel paths, and (2) it can handle a limited number of aircraft encounters at any one time. This system uses only one-way communications techniques.

Non-Synchronous System— One such, called SECANT, has been developed and test flown by RCA. It was especially designed to meet the operational requirements earlier established by the Air Transport Association (ATA) for the time-frequency system. SECANT attempts to measure the bearing of threat aircraft and includes the use of horizontal escape maneuvers (ref. 8).

Interrogator/Responder System— Honeywell has proposed a system which will meet ATA requirements and would sell the airline version for \$6000—\$9000. RCA has described a new version of SECANT called Vertical Escape CAS (VeCAS), which will not attempt to measure bearing of threat aircraft or to use horizontal escape maneuvers (ref. 8).

The ground-based systems are considered more favorable because the FAA is moving to make all VFR traffic transponder equipped. The ground system would require that all aircraft be equipped with 4096 code beacon transponders.

In 1971 the FAA initiated a program called the Discrete Address Beacon System (DABS). System planners NAFEC and MIT Lincoln Labs expect that by 1980 all aircraft would be equipped with a DABS and a cockpit display. A unique identifying number would be assigned each aircraft and each transponder unit would use the same receive and transmit frequencies nationwide, thus eliminating frequency switching. Ground-based radar equipment would determine the aircraft's lateral position; and altitude encoders would transmit the aircraft's altitude over the transponder channel. Using flight plan or other intent information, ground-based computers would evaluate the collision threat and automatically send command information to individual aircraft for display in the cockpit. The airborne portion of the system is estimated to cost between \$1300 and \$1700. The transponder would be compatible with current radar-surveillance ground equipment (ref. 7).

A means to continuously identify aircraft position and velocity would allow flight separations to be reduced, especially in the terminal area (2-mile spacing and 5-second timing error at the final approach gate), and subsequent handling of more traffic and/or the elimination of costly delays. The economic benefits of reducing flight and ground delay time would be evaluated by the airline in terms of cost to develop such an identification system.

Further research in CAS is concerned with the following questions:

- (1) What will be the number and consequence of CAS false alarms?
- (2) What will be the system's effect on arrival and departure rates?
- (3) What will be the effect on ATC when an aircraft makes a sudden evasive maneuver in the terminal area?

Pilot Warning Instrument (PWI)

A PWI is an airborne device which would be used in visual flight rule (VFR) conditions to aid the pilot in visually detecting other aircraft which are a potential collision threat. After visually locating the aircraft, the pilot utilizing the PWI would evaluate the situation and take any necessary evasive action.

Crash Locator Beacons (CLB)/Emergency Locator Transmitters (ELT)

New aircraft delivered after December 29, 1971, must have approved ELT; all others by December 29, 1973. Essentially, approval means meeting the specifications of TSO-91. Jet transports, local training aircraft, "ag" aircraft and certain scheduled operators are excluded. However, some commercial jet aircraft do have CLB's.

NAVIGATION SYSTEMS

Navigation systems include attitude and heading indicators, radio navigation, and self-contained navigation systems such as Doppler and inertial. Airborne radar navigation is used mostly for military missions where terrain avoidance and terrain following are necessary. Radar navigation by map-matching is another technique used by the military where automatic navigation is possible using comparison of the image generated by the aircraft's radar with stored reference images, obtained either from previous missions or predicted. As discussed separately in the section on displays, some radar navigation techniques will be employed by commercial aircraft in the future using moving map displays which necessitate airborne radar as well as a computer. Airborne weather radar which can also be used for radar navigation is discussed in the section on instrumentation.

Radio navigation systems have been the primary navigation systems for years and will continue to be for some time. Doppler navigation and inertial navigation are completely self-contained systems which are used as primary systems only for transoceanic flights. Inertial navigation is considered useful for supporting radio navigation systems on overland flights, but high cost has limited its use to date. Studies are being made to promote the use of inertial systems as the primary enroute navigation system in conjunction with area navigation, and as the primary navigation system in the terminal area where its use is postulated to considerably reduce separation criteria (ref. 9).

Turn and Bank Indicators

The turn and bank indicators (sometimes referred to as the "needle and ball" instrument) is the combination of a gyro operated needle which shows rate-of-turn and a ball which reacts to

gravity and/or centrifugal force to indicate the need for directional trim. This instrument is usually a standby instrument for attitude and directional control; however, the same functions are found integrated in the attitude director indicators (ADI) of transport aircraft.

Heading Indicators

Magnetic Compass— Although most heading or directional indicators used in commercial transports are complex gyro-controlled systems, the magnetic compass is important as a standby, or emergency, directional indicator since it requires no aircraft source of power for operation.

Directional Gyro— The heading indicator commonly used in light aircraft is the relatively simple directional gyro, which has no direction-seeking properties and must be set to headings shown on the magnetic compass.

Compass Systems— This improved gyro-stabilized magnetic compass system consists of the following components:

- (1) Flux Valve unit — the direction sensing device of the system.
- (2) Flux Valve Compensator — compensates for iron error (single cycle), transmission error (double cycle), quadrantal error (due to the physical makeup of the flux valve), and Coriolis error.
- (3) Directional gyro — maintains its reference to magnetic north by signals received from the flux valve.
- (4) Directional indicator — receives heading information from the directional gyro control and presents magnetic heading of the aircraft.
- (5) Amplifier — slaving amplifier and servo amplifiers. Some compass systems receive bank angle and pitch attitude from the vertical gyro and compensates for these errors through electronics in the amplifier in the servo loop.

In some systems the compass amplifier has been replaced by a compass digitizer which presents digital information to the utilizing equipment (ref. 10).

Magnetic Heading Reference Systems (MHRS) – Designed to work with the compass system for use in an aircraft that has an inertial navigation system (INS). The system converts true heading from the inertial platform to magnetic heading using the flux valve and amplifier electronics.

Heading and attitude reference systems use gyros similar to those used in inertial systems except that their cost is far lower and their drift rates are much larger. Gyros widely used are (ref. 11):

- (1) Two Degrees of Freedom (TDF) gyroscopes (sometimes called free gyros);
- (2) Rate gyros;
- (3) Integrating gyros (floated); and
- (4) Double-integrating gyros (using ball-bearing output/axis suspensions).

Radio Magnetic Indicator (RMI)

The RMI consists of a rotating compass card, a double-barred bearing indicator, and a single-barred bearing indicator. The compass card is actuated by the aircraft's compass system and rotates as the aircraft turns. Assuming no compass deviation error, the magnetic heading of the aircraft is always directly under the index at the top of the instrument. The double-barred bearing indicator gives the magnetic bearing to the VOR or VORTAC to which the receiver is tuned; and the single-barred indicator is an ADF needle which gives the magnetic bearing to the selected low frequency facility. There are RMI installations which have selector switches that permit the pilot to use both indicators in conjunction with dual VOR receivers or both indicators as ADF needles. The RMI can be used with RNAV equipment to indicate either the bearing to the waypoint or to the VOR/DME station used to establish the waypoint.

Radio Navigation

The radio systems described here are used for determining position during enroute navigation as well as terminal area navigation. The ground stations are large installations compared to the small and relatively inexpensive airborne equipment required.

Automatic Direction Finder (ADF)— The airborne receiver is tuned to a facility which operates in the 190 kHz to 1750 kHz frequency band. These frequencies include low frequency range stations, non-directional radio beacons (NDB) and broadcast stations. (The military also has a UHF ADF.) The indicator provides automatic visual bearing indication and, if signals are voice or tone modulated, aural reception. Two antennas are necessary for tuning. The receiver is tuned first using the sense antenna to obtain maximum signal clarity; then the loop antenna is selected to indicate the relative bearing of the station from the nose of the aircraft.

ADF provides:

- (1) Enroute position monitoring and position fix data;
- (2) Navigation system where VOR signals are unreliable;
- (3) Radio reception on ground of clearances and weather broadcasts where VHF reception is impossible; and
- (4) Backup navigation information on instrument approaches.

Clearly the ADF is used mainly as a backup navigation system to the simpler operation and interpretation of VHF equipment. Accuracy of all systems (whether fixed, rotated by hand or motor, or fixed/crossed loop) is on the order of 2° exclusive of errors induced by aircraft structure (ref. 11, p. 156).

VHF Omnidirectional Range (VOR)— The VOR (often called the *omnirange* or *omni*) became the United States' communication and navigation standard in 1946 and the international standard in 1949. The equipment operates in the 108.0 to 117.95 MHz frequency band. VOR transmissions are subject to line-of-sight restrictions, and the range of reception varies proportionally to the

altitude of the airborne receiving equipment. The VOR station can be identified by its continuously transmitted three-letter code. The VOR course alignment is generally $\pm 1^\circ$. However, stations located in rough terrain or surrounded by obstructions cause course roughness to be observed. (In light aircraft certain propeller RPM settings can cause VOR Course Deviation Indicator fluctuations up to $\pm 6^\circ$.) Helicopter rotor speeds may also cause VOR course disturbances.

VOR collocated with Tactical Air Navigation (TACAN) is called a VORTAC facility and provides VOR azimuth, TACAN azimuth and TACAN distance at one sight. At each VORTAC facility the VOR and TACAN frequency channels are assigned such that there is a relationship between them in accordance with a national plan to simplify airborne operation.

VOR, VORTAC, and TACAN aids are classed according to their operational use. There are three classes: T (Terminal), L (Low altitude), and H (High altitude).

The normal service range for the T, L, and H class aids is included in Table 1. Certain operational requirements make it necessary to use some of these aids at greater service ranges than are listed in the table. Extended range is made possible through flight inspection determinations. Some aids also have lesser service range due to location, terrain, frequency protection, etc.

Tactical Air Navigation (TACAN)— TACAN is a navigational system developed by the military to provide azimuth and distance information using the same frequency. TACAN is a pulse system which operates in the UHF band of frequencies.

Distance Measuring Equipment (DME)— DME operates on the line-of-sight principle on frequencies in the UHF spectrum between 962 MHz and 1213 MHz. Paired pulses at a specific spacing are sent out from the aircraft and are received at the ground station which then transmits paired pulses back to the aircraft at the same pulse spacing but on a different frequency. The time required for signal exchange is calculated in the airborne DME unit and translated into nautical miles from the aircraft to the ground station. The distance information received is slant range rather than actual horizontal distance. DME furnishes reliable signals at distances up to 200 nmi. at line-of-sight altitude with an accuracy of better than 1/4 mile or 2% of the distance, whichever is greater (ref. 2).

TABLE 1.— NORMAL SERVICE RANGE OF NAVAIDS*

VOR/VORTAC/TACAN NAVAIDS

Normal Usable Altitudes and Radius Distances

Class	Altitudes	Distance
		(miles)
T	12,000' and below	25
H	Below 18,000'	40
H	Below 18,000'	40
H	14,500' — 17,999'	100**
H	18,000' — FL 450	130
H	Above FL 450	100

*Source: FAA *Airman's Information Manual, Part 1.*

**Applicable only within the conterminous U. S.

NON-DIRECTIONAL RADIO BEACON (NDB)

Usable Radius Distances for all Altitudes

Class	Power (watts)	Distance
		(miles)
Compass Locator	Under 25	15
MH	Under 50	25
H	50 — 1999	*50
HH	2000 or more	75

*Service range of individual facilities may be less than 50 miles. See Restrictions to Enroute Navigation Aids, Part 4.

L/MF RADIO RANGES

Usable Radius Distances for all Altitudes

Power (watts)	Distance (miles)
Under 100	40
101 — 200	50
201 — 400	60
Over 400	75

Radio Altimeter— The radio altimeter operates in the 4200-4400 MHz frequency band (civil systems) and indicates height above the surface by measuring the time interval of a vertical signal transmitted from the aircraft to the ground and returned. The radio altimeter output is displayed on the pilot's instrument panel in a circular or linear instrument. Kayton and Fried (ref. 11) discuss the difference between pulse-modulated systems and conventional frequency modulated (FM/CW) systems. Civil systems conform to ARINC Characteristic No. 552.

Altitude Alerter

An altitude alerter (AC 91, 22 July 1969. Required as of Feb. 29, 1972) is mandatory for jet-powered aircraft.

Hyperbolic Systems

Several hyperbolic navigation systems are in use for long-range earth referenced navigation: Decca, Loran, and Omega.

Decca— Decca operates in the 70 to 130 kHz frequency band and is a continuous-wave hyperbolic system. It is used extensively in Europe by ships and fishing fleets, and is used some by aircraft, but is not an accepted standard. Arguments against the selection of Decca as the basic navigation aid throughout the world's airways were that: (1) the ground environment required was regarded as an expensive investment; and (2) strong prejudice against the presentation of primary navigation information on charts that were distorted to the untutored eye.

Loran— Loran-A operates in the 2 MHz frequency band. Loran-A is a long-range aid developed in World War II and is still much in use by transoceanic aircraft. Loran-C operates at 100 kHz and is the expected successor to Loran-A. Loran-C has longer range and improved accuracy obtained by cycle-matching techniques. Range is greater than 1000 miles. Loran-C has less problems with sky-wave contamination. Receiver weight is approximately 25 lbs. Loran-C can be combined with a digital computer to readout longitude and latitude (at doubling of cost and weight). Loran-D operates at 100 kHz and is a short-range tactical system compatible with Loran-C.

Omega— Omega is of special interest because it is being considered as a possible standard navigation system for the future. Omega is an earth-referenced navigation system which operates in the 10 to 14 kHz frequency band and is accurate to 1 nmi. Omega has longer range and less accuracy than Loran-C. Range is greater than 5000 mi. As with Loran-C, Omega is not too good for high speed aircraft. Airborne hardware should eventually be about the same size, weight, and cost as Loran-C. The Omega system is being proposed to reduce lateral lane separation standards over oceanic routes. Using Omega either for surveillance (a means of independently monitoring each aircraft position) or as an onboard navigation aid (updating the onboard dead reckoning system, probably INS) allows the lateral separation to be reduced to 30 nmi. or less (ref. 12). The Omega system would have an impact on navigation in remote areas of the world as well as in the National Aviation System.

At present the northern half of the Western Hemisphere has Omega coverage at reduced power. The Canadian Marconi Company has been able to demonstrate the feasibility of a computerized airborne Omega receiver (3 frequencies: 10.2, 13.6, 11.3 kHz) consisting of: (1) orthogonal loop antenna; (2) antenna pre-amplifier; (3) receiver processor unit (small general purpose computer with 8,000 word memory; computer and machine cycle time basically 1.2 microseconds); and (4) control-indicator unit.

The receiver meets ARINC specifications and is the size of a 1 ATR box. The receiver hardware portion is based on a maximum of digital processing using standard medium-scale integration (MSI) components (ref. 13). The FAA has on-going and planned Omega projects sponsored by the FAA System Research and Development Service (ref. 14). On-going projects include a signal monitoring program in Canada, an airborne signal data collection project in cooperation with N.O.A.A., and an operational evaluation of the AN/ARN-99 Omega System on a commercial airliner. The AN/ARN-99 is a three-frequency, fully automated Omega receiver designed for aircraft applications. Its basic equipment is: (1) Control — Indicator; (2) Receiver — Computer; (3) Antenna — Coupler. Planned projects include evaluation of a differential Omega system, development of a 3.4 kHz or composite Omega airborne system, evaluations of low cost VLF/Omega equipment, and development of a civil aviation Omega system which would incorporate the most promising techniques found in preceding investigations.

Satellite Navigation Systems

Rodrick and Fine (ref. 15) discuss computers for satellite navigations systems being postulated for the future which will provide constant, global all-weather coverage, with three-dimensional position accuracy measured in the tenths of feet and velocity accuracy measured in tenths of a foot per second, and with data rates as high as ten per second. The navigation satellite systems which are discussed are:

- (1) Active Ranging;
- (2) Range Difference (Passive);
- (3) Pseudo Range (Passive Ranging);
- (4) Range Rate (Active);
- (5) Pseudo Range Rate (Passive); and
- (6) Angle Measurement Position Determination.

Very Low Frequency (VLF)

The frequency band usually reserved for submarines is being considered by the FAA as a supplement to VHF in civilian aircraft navigation systems.

Doppler Navigation

The previously discussed methods of fixing position are based on externally referenced systems. Doppler radar and inertial techniques are wholly self-contained aids. The Doppler radar system has been found to be an extremely accurate ground speed and drift system which is totally independent from ground based equipment. Advantages are that it:

- (1) is very accurate (0.1% velocity error),
- (2) is useful for helicopter and VTOL aircraft because it measures negative speed,
- (3) is self-contained,
- (4) is all-weather,
- (5) can be used over oceans, etc.,
- (6) does not require preflight alinement or warmup.

In the Doppler system, the velocity sensor is a Doppler radar which transmits RF energy to the ground and measures the frequency shift in the returned energy to determine ground speed; the computer is smaller and simpler than in inertial systems. Like inertial systems, however, Doppler position accuracy degrades with increasing distance traveled. Price is \$15,000–25,000 including radome; weight is 40–60 lbs.

Inertial Navigation

An inertial navigator is a self-contained system which measures velocity and position by measuring force and processing the information in a computer. The following advantages and disadvantages are cited for inertial navigation systems (ref. 11).

Advantages:

- (1) Indications of velocity and position are instantaneous and continuous;
- (2) Self-contained and non-jammable;
- (3) All-weather;
- (4) Not affected by vehicle maneuvers (in contrast to Loran and Doppler);
- (5) Accurate.

Disadvantages

- (1) Position and velocity information degrades with time;
- (2) Expensive;
- (3) Relatively difficult to maintain and service;
- (4) Initial alinement necessary.

In an inertial navigation system, the accelerometers are the devices which sense force. Accelerometer designs used in aircraft inertial navigation systems today include: (1) Floated pendulum; (2) Pendulum, supported on flexure pivots; and (3) Vibrating string or beam. The floated-pendulum and the flexure-pivot accelerometers are most commonly used in aircraft systems (ref. 11). The gyroscopes provide a frame to which the force measurements can be referenced. Several types of gyroscopes are presently used in aircraft systems:

- (1) Two-degree-of-freedom (TDF) floated gyros,
- (2) Single-degree-of-freedom (SDF) floated gyros,
- (3) Single-degree-of-freedom (SDF) non-floated gyros.

The TDF gyro (sometimes called free gyros) consists of a balanced rotor held in gimbals and pivoted inside a case. The SDF gyro is essentially a TDF gyro with one gimbal axis fixed, leaving only one gimbal axis of freedom. SDF gyros are considered more complicated than TDF gyros and are classified as: (1) rate gyro, (2) integrating or rate-integrating (also called floating) gyro, and (3) unrestrained or double-integrating gyro.

Some unconventional gyros being developed for inertial navigation system applications are: (1) electrostatic gyro, (2) laser, (3) fluid, (4) cryogenic, and (5) nuclear.

There are two gyro systems:

- (1) *Gimbal*— a mechanical system which physically moves the gyros in the gimbal system to keep the stable member (the accelerometers are mounted in the stable member) in a known inertial orientation. The gimbals physically move to null out error signals from the gyros (i.e., the gyro mounted in the x-position feeds the gimbal in the x-position). Commercial systems are pseudo 4-gimbal systems where the fourth gimbal is either 0 or 90°.
- (2) *Strapdown*— in this system the gyros are fixed to the vehicle and the stable member is a mathematical concept fixed in the computer. The gyros feed error signals to the computer, where the inputs go into a rotational matrix which puts the accelerometers in an inertial frame of reference, so instead of physically moving the stable member, it is kept in the computer. As computer costs come down, strapdown systems will see more use.

Both gimbal and strapdown systems use SDF and TDF gyros; three SDF gyros are needed to construct a platform. The AC Electronics Carousel IV system, for instance, uses two TDF gyros, which gives one redundant axis.

The Strapdown Inertial Reference Unit (SIRU) being evaluated at Ames Research Center is a six-axis system having six accelerometers and six gyros arranged in a dodecahedron-orthogonal mounting configuration. Each gyro/accelerometer measures more than one axis; reliability increases because two gimbals can be allowed to fail and the system still is operational. This requires a large computer because the computer needs to look at gyro and accelerometer inputs at a high rate: the more often the mathematical stable member orientation is constructed from gyro inputs, the less error is propagated. SIRU has a 20 millisecond computation cycle.

A new rate-of-turn sensor which would replace spinning mass gyros in conventional applications is the vibrating wire rate sensor (VWRS), being developed by Honeywell, Inc. Advantages of the VWRS are that it is relatively insensitive to temperature, requires less than one watt power, and has no detectable hysteresis effect (ref. 16).

In 1970 a study was made by Litton Systems, Inc., of the application of inertial navigation to terminal area navigation (ref. 17). Limited demonstrations in the Los Angeles terminal area, made using an FAA Convair C-580 equipped with a Litton LTN-51 Inertial Navigation System updated by two ARINC 568 digital DME's, were encouraging. In 1971 tests were made using the INS/DME/DME system integrated with an optically projected moving map display, provided by the Astronautics Corporation of America.

Litton Industries is developing an inertial navigator employing multiple function inertial instruments to perform the roles of accelerometer and gyroscope in a single device (ref. 18). The existing pair of TDF gyros and three accelerometers will be replaced by two multisensors. Thus the platform size will be reduced with modest performance improvements and an unspecified savings in cost.

The implications are that: (1) more aircraft will have inertial systems since it provides an independent system with instantaneous attitude, azimuth, position, velocity, and track angle; (2) high accuracy but relatively costly systems will be used mainly by military; and (3) moderately accurate, low cost systems will be used for a wide variety of military and commercial aircraft.

Inertial Navigation Systems conform to one of two ARINC characteristics:

Characteristic 561— Air Transport Inertial Navigation System (INS) defines a full inertial navigation system including area navigation computer with provision for pre-set waypoints and with an output suitable for connecting directly to a flight director and autopilot (ref. 19).

Characteristic 571— Inertial Sensor System (ISS) defines a simpler system which outputs longitude, latitude, and drift angle, but no platform outputs such as pitch, roll, vertical acceleration.

Area Navigation (RNAV)

RNAV systems allow the defining of a waypoint by selecting a range and bearing to the destination using VOR and DME (Rho/Theta system) or by simultaneous readings from two remotely-located DME stations (Rho/Rho system). Thus the aircraft can operate on any desired course within the coverage of station-referenced navigation signals or within the limits of self-contained system capability such as inertial (ref. 2). Inertial navigation systems require automatic or manual updating. Manual updating presents a significant increase in pilot workload. Doppler radar, Omega, Loran A and C, satellite and very low frequency navigation systems are all considered unfeasible for various reasons.

A joint manufacturer/user advisory group has been assembled by the FAA to formulate a three-phase, 10-year program for introduction of RNAV (ref. 20). The joint task force has settled on the VOR-DME based (Rho/Theta system) type as the most feasible. The joint task force has also made the following recommendations outlining performance requirements for airborne equipment:

- (1) VOR receiver accuracy of 1.0° ;
- (2) DME accuracy to 0.25 mi.;
- (3) Automatic DME slant range correction above 18,000 ft;
- (4) RNAV signal output displayed on normal flight instruments; RNAV routes programmed to permit coupling to AP or FD.

- (5) VNAV signal output shown on the navigation guidance display;
- (6) Parallel offset, including turns and intercepting offsets, which permits 1 nmi. increments out to 10 nmi. and 2 nmi. thereafter out to 20 nmi.;
- (7) Turn anticipation prior to the waypoint, which would allow smooth interception of the next leg;
- (8) VNAV climb or descend initiation prior to reaching climb or descend point;
- (9) Simple manual insertion of waypoints, storage of at least 6 waypoints for RNAV equipment, and 10 waypoints for VNAV equipment;
- (10) Total system and subsystem fail indicators;
- (11) System for pilot verification of inputs.

Anticipated benefits of RNAV are: (1) reduced cockpit workload, especially in the terminal area; and (2) simpler and reduced interface between the cockpit crew and controllers. Area navigation concepts are described by three ARINC characteristics:

- (1) ARINC 581 Mark 1 system -- The simplest; uses VOR/DME inputs or latitude/longitude inputs from INS.
- (2) ARINC 582 Mark 2 system -- Uses a general purpose digital computer to mix inertial, terminal VHF radio or Loran/Omega radio signals and to interface with an electronic map.
- (3) ARINC 583 Mark 13 system -- Evolved from industry schemes for common wiring, compatible equipment boxes and pin connectors for ARINC 561, 571, Mark 1, or Mark 3. (Old ARINC 562 Mark 3 was actually an extension of inertial Characteristic 561 enabling aircraft inertial position to be updated in the terminal area from VOR/DME inputs using additional computer capacity in an accessory or auxiliary unit.)

In the United States, the Butler National Vector Analog Computer (VAC) was one of three area navigation systems compared by American Airlines for STOL applications. The Butler VAC

was compared with a Litton LTN-51 inertial system and a Decca Omnitrac. The Decca Omnitrac was used both within a Decca hyperbolic chain and actuated by conventional VOR/DME inputs. The systems were flown using a McDonnell Douglas 188 in the New York, St. Louis, and Chicago areas. Then the Butler systems were installed in two American Airlines Boeing 727's on short-haul operations between Chicago and New York. The Butler National VAC consists of:

- (1) Symbolic Pictorial Indicator, which is in the form of a course director instrument and indicates distance off track as well as distance to go or distance run from a DME waypoint and simultaneously displays distance to the actual DME station.
- (2) Dual Waypoint Selector Unit.
- (3) ADD Unit, which allows altitude to be gained or lost over a predetermined distance to be dialed in; then the computer will calculate the point at which the climb or descent should begin and will provide guidance through the conventional ILS indicator.

The total price of the Butler VAC system is about \$16,000 (ref. 21).

Eastern Airlines conducted similar area navigation system studies in 1968 and 1969 on its short haul routes from Boston to New York and Washington with emphasis on the Decca Omnitrac system. The Omnitrac system consists of: (1) Omnitrac computer developed in 1964 to provide representational charts for the Decca pictorial display; however it is capable of accepting inputs from the long-range Loran or Doppler equipment to the short-haul VOR or DME; and (2) pictorial display. Eastern's decision was to specify the Omnitrac system for all its short-haul routes and for its DC-9 fleet. The basic Omnitrac costs approximately \$45,000 which does not include the equipment to provide the inputs required by the user.

During 1973 United Air Lines will evaluate RNAV in a DC-10 using a pre-production model of a Delco ARINC 583 Mark 13 RNAV system, a Carousel inertial unit and two switching units that will allow the RNAV system to be connected to the autopilot, cockpit instruments and navigation receivers without modifying those units (ref. 22).

Vertical Navigation System (VNAV)

Vertical Navigation Systems add the third dimension of control to area navigation (RNAV) systems (ref. 23). (The further addition of time at a waypoint will complete the concept of volumetric navigation.) Vertical guidance equipment will:

- (1) Permit aircraft operation along vertical corridors with pre-established departure climb gradients, enroute altitude changes, terminal descents, approaches to noninstrumented runways, interception of ILS approach paths, and missed approach procedures.
- (2) Permit aircraft operation along more complex vertical flight paths for such purposes as obstacle, traffic, or wake turbulence avoidance, noise abatement, operational efficiency, or passenger comfort.

FLIGHT CONTROL SYSTEMS

Some form of the automatic flight control system (AFCS) is found on all jet transports, varying from an autopilot to the quadruplex fly-by-wire system proposed for future transports. A basic stability augmentation system is described as an introduction to the automatic flight control system including the autopilot. The flight director system is discussed in this section because of the trend toward integrated autopilot/flight director systems as on the Boeing 747, DC-10, and L-1011. Elsewhere the flight director system is often found listed with instruments or navigation systems for cost and weight itemizing purposes. A flight control system which consists of either an autopilot with an approach coupler or a flight director system is required for Category I operations (see LANDING SYSTEMS).

Stability Augmentation Systems (SAS)

This is the basic stabilization system incorporating two- or three-axis stabilization. The SAS maintains the aircraft's straight and level attitude by sensing roll and yaw disturbances. Proper corrections are applied to the aircraft's control surface through a pneumatic metering system. The

pitch control system may be a separate device consisting of sensors independent of standard flight instruments, or may use inputs from air speed, rate-of-climb, and the attitude gyro. Servos provide correction to the elevator. In transport aircraft these systems are combined with heading reference systems, altitude hold systems, and attitude hold systems in some form of an autopilot or automatic flight control system.

Autopilot (AP)

The AP is used for stability augmentation, to improve damping in roll, pitch, and yaw, and to improve pilot handling qualities. The AP equipment includes sensors, controllers, electronics, actuators, and displays (ref. 11). Since the equipment directly moves the controls affecting the flight of the aircraft, it is designed for high reliability and has a large influence on the design of the aircraft control surfaces. Generally, the equipment is provided by suppliers working closely with the airframe manufacturers. Traditionally, the electric power supply has been 400 Hz ac but now dc is more commonly supplied because of the use of microcircuits. Low cost microcircuits encourage redundancy, thus creating higher reliability. The autopilot computer is conventional analog, or more frequently digital, with replaceable circuit cards and boards mounted in a standard ATR rack. The actuators are electromechanical or hydraulic depending on requirements; electromechanical actuators are usually furnished by the autopilot manufacturer, hydraulic ones by airframe manufacturer as part of the hydraulic system.

Automatic control systems are classified according to the various methods of control as on-off control, stepwise control, and continuous control systems (ref. 24). An automatic control system is a closed-loop system which is characterized by feedback from the output to the input. A special type of feedback control system is a *servomechanism*, in which the directly controlled variable is a direct function of a position or speed. Another type of feedback control system is a *regulator* in which the output is maintained at a preset value regardless of input variation. A necessary part of an automatic control system is an *error detector*. Some such are: (1) a transducer, (2) a single-ended potentiometer or a double-ended potentiometer, and (3) a synchro (there are four basic types — transmitter, receiver, transformer, and differential).

The autopilot may be engaged in any reasonable attitude either coupled to or uncoupled from the flight director. When coupled, the autopilot will acquire the commanded flight path and continue to accept guidance commands from the flight director system. When engaged and uncoupled, the autopilot accepts pitch and roll commands from the autopilot controller which is located in the cockpit and enables the pilot to select modes and introduce commands to the autopilot. With the increased use of microelectronics, the trend is to include a significant part of the mode-selection electronics in the controller package.

Flight Director System (FD)

The flight director system graphically consolidates navigation and attitude information and presents computed steering commands to the pilot. The FD system consists of electronic components which compute and indicate the aircraft attitude required to attain and maintain a pre-selected flight condition. The system components include a control panel, a flight director indicator, a course indicator, a flight computer, and a flight instrument amplifier.

Control Wheel Steering (CWS)

Control Wheel Steering allows the pilot to take over command for short-term manual maneuvering without the need to disengage and reengage the autopilot.

Yaw Damper

Although the yaw damper is sometimes considered part of the autopilot, it is a separate system and is not dependent on autopilot operation. The yaw damper controls only the rudder and is intended to be used in all phases of flight. In the Boeing 707 (ref. 25), yaw is sensed by the yaw rate gyro in the yaw damper coupler which sends rudder displacement signals to the rudder power control unit. (Hydraulic pressure inputs are made to the rudder actuator to correct the yaw.)

Approach Power Control/Autothrottle/Speed Control

Approach power control, frequently referred to as autothrottle, holds the aircraft at a pre-determined angle of attack or airspeed. Sperry makes an autothrottle for the DC-8 and the DC-10 and for some B-727's, which is separate from the autopilot. The desired airspeed is selected for cruise or approach and the autothrottle reduces or increases power as necessary to maintain the selected airspeed. The system for the proposed DC-10 Twin (ref. 26), called an Autothrottle/Speed Control (AT/SC), provides the following functions:

- (1) Pitch command signals for the FD, AP and slow-fast display;
- (2) Airspeed or stall margin control through automatic (autothrottle) or manual (slow-fast display) throttle control;
- (3) Automatic engine thrust control;
- (4) Rate of retard control and fast retard control;
- (5) Stall warning as a function of angle of attack; and
- (6) Auto slat extension during clean configuration stall conditions.

Command Augmentation System

Usually not considered a separate system in current commercial transports, the command augmentation system includes such functions as: (1) control through the pitch, roll and yaw axes with cross-coupling signals from thrust, direct drag and direct lift controls; and (2) thrust management through throttle and incremental flap control.

Independent Landing Monitor (ILM)

The ILM is a fully independent system proposed to provide guidance information during the landing operation using external sensors rather than interpreting radio information. It is still in the experimental stage.

Automatic Landing Systems

Onboard guidance systems are closely related to the associated ground equipment. The ground systems associated with an automatic landing and the airborne requirements specified by the FAA for an airborne system to be certified for Categories I, II, and IIIa conditions will be discussed in the section on LANDING SYSTEMS.

As discussed by Fried (ref. 11), most landing system designs consist of onboard guidance using radio beams with a radio altimeter to transition from the radio approach to touchdown. In some cases radar guidance is provided the crew by a ground facility. Whether guidance is provided by the ground controller or calculated onboard, either there is crew control (where the crew flies the aircraft manually following flight director signals), or there is autopilot control (the steering signals are directly input to the autopilot with the crew monitoring the landing). In the past few years, automatic landings using automatic flight control system with an autoflare computer have become more commonplace. The difference between these systems and a *fully* automatic landing system is the control of the aircraft on the runway. Full Category IIIc landings will not be possible until adequate runway guidance is available.

Fly-By-Wire Control Systems

A fly-by-wire system has the following advantages (ref. 27):

- (1) Capable of automatic programming;
- (2) Control system inertia is minimized;
- (3) Thermal effects on the control cable, linkage, and structure are eliminated;
- (4) Control deflections induced by structural deflections are eliminated;
- (5) Control system friction problems are eliminated;
- (6) System free play is minimized; and
- (7) Interconnect mechanisms are eliminated.

The flight control system for the space shuttle orbiter utilizes a fly-by-wire approach in which electronic signals are received from the avionic system by four-channel, electrohydraulic force-summing secondary actuators. The signals are voted in the secondary actuator and summed as a

mechanical output to position the surface actuator. In place of a wheel, a side arm controller is moved fore and aft and laterally to produce command signals which are obtained from force transducers located in the respective system feel cartridge. The force transducer output signal is transmitted to the computers to be summed with aerodynamic, vehicle motion, and control law signals. The resultant command signal is transmitted to the servocontrol actuator and to monitor electronics which position the surface actuators. The servoloop is completed when the servocontrol actuator position and monitor signals are sent back to the monitor electronics.

The flight control system of future transports may be similar to that planned for the shuttle. The mechanical system would be replaced by a quadruplex fail operational/fail operational/fail safe fly-by-wire system. Active control technology could provide dynamic and static stability.

INSTRUMENTATION

The need to improve the operational capability of the aircraft has placed greater emphasis on the functional integration of subsystems which have been treated independently in the past. It has become apparent that communication, navigation, and flight control cannot be treated in isolation but have to be considered along with instrumentation as a total operational system. Instrumentation includes the air data system, weather radar, clocks, flight recorders, potential clear air turbulence detectors, and displays.

Air Data System

The Air Data System is composed of sensors and computer or computers. Sensors measure the air characteristics (static pressure, total pressure, air temperature, angle-of-attack) which transducers convert into electrical signals. The computer(s) calculates true airspeed, free-stream static pressure, free-stream outside air temperature, and Mach number, angle-of-attack, etc., and drives displays, sets autopilot, and controls the cabin air conditioning system. Duplicate computers are often used to drive the pilot's and copilot's displays. The computer incorporates automatic checkout features

such as internal-failure-monitoring, comparison monitoring between duplicate computers, and self-test circuits. Air data systems are found on all modern jet commercial transports; however, digital air data systems are found only on the latest generation jets.

The air data system proposed for the Concorde is a pair of Crouzet analog air data computers. The use of digital air data computers is being considered, since significant increases in reliability (as much as a factor of 2 over analog machines), computing accuracy, and flexibility could be realized (ref. 28). However, the Concorde air data system must interface with much equipment which is not digital. In contrast to the DC-10 digital air data computer, the Concorde computers have 68 outputs, more than twice the number for the DC-10. The Concorde digital computers would meet the ARINC 575 characteristic for a digital machine having analog outputs. The DC-10 digital air data computer meets the ARINC 576 characteristic for a digital computer having digital outputs. ARINC characteristics for air data systems indicate the various degrees of sophistication:

545	Subsonic Air Data Computer System
545A	Mark 1-1/2 Subsonic Air Data System (ADS)
565	Mark 2 Subsonic Air Data System
575-3	Mark 3 Subsonic Air Data System (Digital) – (DADS)
576	Mark 4 Subsonic Air Data System (All Digital Outputs) – (DADS)

Air Data System indicators include:

- Mach/Airspeed
- Barometric Altimeter
- Vertical Speed
- Standby Altimeter
- Standby Indicated Airspeed

Angle of Attack/Stall Warning System

All transports have an angle-of-attack vane located on the side of the fuselage. The main function is for the stall warning system. A separate angle-of-attack readout is available and requires a separate indicator. In some aircraft an angle-of-attack input to the flight control system controls aircraft pitch for constant angle-of-attack rather than airspeed.

Clocks/Electronic Chronometer System

Each clock has a 12-hour dial, conventional hour and minute hands, and a sweep second hand. All clocks have an elapsed time feature which consists of a control and an elapsed time dial. Some clocks have an additional dial for logging minutes.

The steadily advancing state-of-the-art in communications and navigation systems has generated requirements for increased accuracy of time and frequency reference standards. Between 1920 and 1965 there was an increase in the required accuracy of frequency reference standards of about an order per decade (ranging between parts in 10^5 to a part in 10^{10}). Between 1965 and 1971 there was an increase in the requirements by about a factor of 1000. During that same time span, the required accuracy for time increased from approximately 1 millisecond to 5 microseconds. Present communications systems involving high data rates and navigation systems operating in the RHO RHO mode require the latest in frequency time standards. There is an ARINC Characteristic 584 on Electronic Chronometer Systems; however, none are being produced.

Flight Data Recorders

Flight Data Recorders are required by FAA regulation for recovery of data after an aircraft accident or incident. ARINC Characteristics 542 specifies an analog recorder which records data on thin metal tape for retrieval purposes. A few years ago the FAA increased the number of parameters required to be recorded. ARINC Characteristic 573 for Aircraft Integrated Data Systems specifies a general purpose data acquisition system which acquires the mandatory data as well as standard general purpose data.

Aircraft Integrated Data System (AIDS)

AIDS are recording and checkout systems which are mainly engine monitoring. The automatic data recorder replaces manual data recording during flight by the first officer. In some cases recorded data must be taken off the aircraft and delivered to the airline maintenance base for data reduction by computer. AIDS are envisioned to eventually encompass a total system including data formatting, data processing, and display.

Airlines use several types of system configurations. Those airlines having a hub-type route place less emphasis on a capability to transmit recorded maintenance data to their maintenance base than airlines having other route systems. Airlines having dispersed facilities tend to use a non-continuous maintenance recorder plus a separate performance recorder while others tend to use one recorder for both. Airlines with no requirements for quick response may use large capacity recorders and remove the tape cassette only once a week, while a few airlines may have complete onboard processing.

ARINC 563 defines the AIDS Mark 1 data acquisition unit, a general purpose standard (as opposed to mandatory for accident recovery) data acquisition unit capable of interfacing with various other AIDS equipment including a cassette-loaded long-term recorder, a crash protected recorder, a control unit, and a logic unit. This system is in use by such operators as American Airlines, TWA, Alitalia, and BOAC (ref. 29).

ARINC 573-5 defines the AIDS Mark 2 flight data acquisition unit (FDAV) and its interfaces with a flight data entry panel (FDEP), digital flight data recorder (DFDR), accelerometers, and AIDS. This unit features programmable inputs, allowing full interchangeability between different aircraft types; and, it satisfies both U. S. and European mandatory requirements.

Most airlines use AIDS primarily for maintenance support as opposed to flight safety monitoring, and concentrate AIDS on engine monitoring (ref. 30). The AIDS system is still a new concept which itself has problems in reliability, maintenance, and the necessity for data reduction. Boeing 747's have been retrofitted with ARINC 563 systems. Lockheed and McDonnell-Douglas have selected the ARINC 573 system for their L-1011 and DC-10.

Airlines as well as avionics manufacturers question the cost effectiveness of AIDS. The basic AIDS system offered on the DC-10 cost \$100,000. No carrier has the full AIDS system as described in ARINC 573. United Air Lines has the basic system installed as it is delivered from McDonnell-Douglas with provisions for engine monitoring, but has not yet installed the transducers (ref. 31). United has worked closely with American Airlines to standardize the DC-10. However, United feels that it cannot justify the cost of a full AIDS system because the reliability of the AIDS system has not been developed to better than what is being monitored.

The AIDS system described by ARINC 573 is well within today's state-of-the-art. However, its cost effectiveness must be justified by the users. As a maintenance tool AIDS must pay its own way; it must do more real-time assessment. AIDS's capability as a tool for flight operations management will be demonstrated when it is part of a total system (see FUTURE REQUIREMENTS).

Weather Radar

Federal Air Regulations Part 121 requires weather radar for operation under transport category rules. Weather radar provides weather detection and is often combined with navigation radar to provide ground mapping as a secondary function. Designs are found in several bands although the X-band is most frequently used for high performance commercial jet aircraft because it requires a smaller antenna and waveguide size for equivalent gain and resolution (ref. 11). At X-band, the general regions of weather may be seen; although the radar may be unable to penetrate the region to detect local areas of severe weather, such as thunderstorm cells. At C-band, the radar is usually able to penetrate the region to see such cells. Thus, X-band is often called "weather avoidance" radar and C-band is called "weather penetration" radar. There are some designs available at K_u-band.

Ground radar detects hazardous weather conditions and can vector both visual and instrument flights around the areas of severe weather.

Clear Air Turbulence Detector

A practical clear air turbulence (CAT) detector has not been achieved. Tests are being conducted; the major ones are:

- (1) Pan American World Airways Boeing 707 using infrared detection equipment by Barnes Engineering Company to correlate turbulence with temperature anomalies (ref. 32).
- (2) Continental Airlines Boeing 747 with the National Center for Atmospheric Research using infrared sensor to relate turbulence to rate and magnitude of temperature change (ref. 32).

- (3) NASA Flight Research Center B-57 carrying DOD-sponsored prototype radiometric sensor to receive microwave signals associated with the air temperatures ahead of the aircraft (ref. 33).
- (4) NASA Marshall Space Flight Center is considering future flight research programs using laser Doppler technology (ref. 33).

Displays

Display systems on transport aircraft can be described best as improved control-display systems which are partially, but not fully integrated. Fully integrated avionics systems which are postulated for the 1980's will eliminate individual black boxes and their associated indicators. Instead, a systems architecture of some kind will be developed wherein guidance and navigation information is received and processed by a central computer or multiprocessors and displayed pictorially on one or several multifunction displays. Extensive ongoing research and development work will result in specialized display systems which will reduce pilot work load, as well as increase pilot capability to handle the demands of instrument flight and landings in all weather conditions.

Displays may be described as *situation* displays in which the instrument gives the pilot an indication of his attitude, altitude, airspeed, or heading and the pilot must decide what to do with this information; and, as *command* displays in which "fly left," and "climb," instructions are indicated, and in some cases speed is also used. The flight director combines situation and command information in full view of the pilot. Fried (ref. 11) describes five basic categories: continuous or analog; digital; symbolic (course indicator); directed motion (peripheral command); and pictorial, or contact analog.

Head-Up Displays (HUD)

The problem of transition from instrument to visual flight has been approached using head-up display (HUD), which permit the pilot to fly on instruments while looking through the windshield. Although these displays are experimental for commercial transports, some of the types being evaluated are: (1) *projection* from a cathode ray tube of a symbolic pattern viewed through the

windshield as an image focused at infinity; (2) presentation of information on a *transparent panel* located above the glare shield; and (3) *directed motion* display devices located within the peripheral view of the pilot.

Vertical Tape Instruments

Vertical tape instruments are being used increasingly instead of round dial type indicators, particularly for air data systems and engine indicators. Vertical tape instruments allow better panel organization, economical use of panel space, and improved readability.

Map Displays

Map displays are beginning to appear in transport aircraft, particularly those equipped with area navigation systems. Several types of map displays have been tried, for instance, strip chart, manual chart change, back screen projection of charts on filmstrips, integration of cathode ray tube projection with hard-copy charts, and television display of surveillance radar information. The projected map display has the following advantages in contrast to the cathode ray tube (ref. 28):

1. density of stored data,
2. little risk of scrambling information,
3. minimum computer demand,
4. shorter access time,
5. data presentation in a familiar manner.

Advantages of the cathode ray tube are:

1. flexibility,
2. ease of replacing tape cassette rather than film as the maps become dated.

The moving map display which will be offered as an option on the Concorde uses stored film such that an airline like BOAC would be able to put its complete route network on a single roll of film (ref. 28).

Integrated Flight System

The integrated flight system found on virtually all jet transports required to operate in low visibility conditions consists of two instruments which combine the functions of many separate indicators of a nonintegrated panel. The two instruments are called an Attitude Director Indicator (ADI) sometimes called a Flight Director Indicator, and the Horizontal Situation Indicator (HSI) sometimes called a Course Indicator. The basic ADI layout includes (ref. 34): Aircraft symbol, Flight director command bars, Attitude sphere, Roll attitude pointer, Glide-slope deviation indicator, Localizer deviation indicator, Radio altitude, Speed command, and Flags.

The basic HSI performs the following functions: Heading display, Course selection, Course readouts-digital and analog, Cross-course displacement display, To-from indication, Heading selection, Selected heading readout, Glide path deviation display, Distance display, Navigation mode annunciation, Monitoring, and Warning flags.

Electronic Displays

The Electronic Attitude Director Indicator (EADI) and the Electronic Horizontal Situation Indicator (EHSI) are advanced electronic display concepts which present the information normally available to the crew from the ADI and the HSI on a panel mounted display by use of electronically generated symbology.

LANDING SYSTEMS

The transport aircraft must make an approach to and land at airports where weather conditions may include low visibility, low ceiling, crosswinds, storm activity and poor runway taxi conditions. The aircraft must execute either a *precision approach* procedure (standard instrument approach in which an electronic glide slope is provided) or a *non-precision approach* (no electronic glide slope is provided). Non-precision approaches are NDB, VOR, LOC, TACAN, LDA, VORTAC, VOR/DME or ASR. Precision approaches are ILS or PAR. The ILS approach can be made to Category I, II, or III minimums if the airport has an approved Category I, II, or III procedure, and the aircraft and crew are certified for operation in that category.

The ultimate goal is a landing system that provides uniformly safe guidance in all weather conditions, called the "all-weather landing system." Toward this goal the FAA will implement a Microwave Landing System (MLS) which will eventually replace the conventional ILS.

Instrument Landing System (ILS)

The ILS is a low-altitude approach system which consist of ground equipment that works in conjunction with airborne receivers and antenna. As discussed by Kayton and Fried (ref. 11) the ground equipment consists of:

(1) *Localizer (LOC)* which provides lateral steering signals for front-course and back-course approaches to the runway. The localizer antenna which is situated a few hundred feet beyond the stop end of the runway is 5 to 18 ft high, and consists of eight loop antennas in a linear array. Since it is a continuous wave type, bends in the course result from reflections from surrounding terrain, buildings, taxiing and airborne aircraft, and ground vehicles. Two localizer arrays may be used for especially difficult sites: a clearance array and a directional array.

(2) *Glide Slope (GS)* which provides vertical guidance signals for front course only. The transmitter is located in a building approximately 750 to 1,250 ft from the approach end of the runway, between 400 and 600 ft to one side of the centerline. The null-reference glide-slope array consists of two antennas on a mast, one 14 ft above ground and one 28 ft high (for a 3° glide slope). The *glide path* is that portion of the glide slope which intersects the localizer.

(3) *Marker Beacons (MB)* which provide distance checks at two points along the front course, transmit on a frequency of 75 MHz in two fan-shaped beams along the approach path and perpendicular to the approach path. The outer marker (OM) is located at the point where the glide path intersects the minimum holding altitude, about 4 to 7 mi from the runway. The middle marker (MM) is located at the point where the glide path is 200 ft above the runway, approximately 3,500 ft from the approach end of the runway. Some ILS have an inner marker to identify the decision height (DH), however use of the inner marker to identify the DH is being replaced by use of an airborne radar altimeter.

A compass locator is a low-powered non-directional radio beacon operating in the 200–400 kHz frequency band. When part of an ILS front course, compass locators are colocated with the outer and middle marker (LOM and LMM).

(4) *Approach Light System (ALS)* which provides a means of transition from instrument-flight to visual-flight. Figure 1 indicates the different United States Approach Lighting Systems. Category II runway lighting consists of:

- (a) a row of white decision lights located 1000 ft from the approach end of the runway,
- (b) red and white light bars,
- (c) green threshold lights,
- (d) runway flush light bars,
- (e) center-line flush lights, and
- (f) edge lights.

Figure 1.— The United States Approach Lighting Systems
indicated on Airport Diagrams.

- Ⓐ ICAO Standard, Integrated Visual Approach and Landing Aid (IVALA)
- Ⓐ₁ U. S. Standard (A)
- Ⓐ₂ Short Approach Light System (SALS)
- Ⓐ₃ Medium Intensity Approach Light Systems with Runway Alignment Indicators (MALSR)
- Ⓐ₄ Medium Intensity Approach Light System (MALS)
- Ⓑ U. S. Configuration (B)
- Ⓓ Navy Parallel Row and Crossbar
- Ⓔ Two Parallel Row
- Ⓕ Left Row (High Intensity)
- Ⓖ Navy Composite
- Ⓘ Air Force Overrun
- Ⓥ Visual Approach Slope Indicator (VASI)

Many airports have installed supplementary lighting including: a high-intensity flasher system which consists of a series of brilliant blue-white bursts of light flashing in sequence along the approach lights (giving the effect of a ball of light traveling towards the runway); Runway End Identifier Lights (REIL) which consist of a pair of synchronized flashing lights, one located on each side of the runway threshold; and Visual Approach Slope Indicator (VASI) lights which provide visual glide slope information. VASI consists of 12 light source units: 3 on each side of the runway 600 ft from the threshold and 3 on each side 1,300 ft from the threshold. Each unit projects a light beam having white in the upper part and red in the lower part. When on the glide path the downwind light units appear red and the upwind units appear white. These lights are visible at the outer marker weather permitting.

Visual Approach Path Indicator

The Visual Approach Path Indicator (VAPI) light system manufactured by Lockheed Aircraft Service Company is a triple beam light (red, green, and amber) which is directed outward in a conical pattern from the threshold end of an airport runway. VAPI light beam angles can be varied to meet unique clearance requirements of specific airports. After intercepting the VAPI light cone, the pilot must determine if he is high (amber) or low (red) or right on (green). On a clear night, the VAPI light signal is visible for 10 mi or more. Although VAPI and the improved VAPI II are installed in more than 200 airports in the United States, the FAA is still testing the VAPI and no VAPIs are listed in the Airmans Information Manual (ref. 35).

International Civil Aviation Organization (ICAO) Weather Categories

The ICAO has defined weather categories as follows:

Category I: 200-ft decision height and 2,400-ft visual range.

Category II: 100-ft decision height and 1,200-ft runway visual range.

Category IIIA: 700-ft runway visual range.

Category IIIB: 150-ft runway visual range.

Category IIIC: Nonvisual touchdown operation.

Figures 2 and 3 indicate the required equipment in addition to the instrument and radio equipment required by the Federal Aviation Regulations to be the minimum airborne equipment considered necessary for Categories I, II, and IIIA operations.

Figure 2.— Airborne Equipment Requirements
Categories I and II*

Minimum Requirements	CAT I	
	(Turbojet Only)	CAT II (All Aircraft)
Single Flight Director 1/ <i>or</i>	Required	Minimum requirement — Two-engine propeller aircraft only.
Single Automatic Approach Coupler 2/		
Instrument Failure Warning System	Optional 3/	Required plus flight crew assignments and procedures specified in Note 3/ below.

Additional Category II Requirements*

Dual ILS and Glide Slope

Receivers

Single Flight Director with Dual Displays 1/ *and* Single Automatic Approach Coupler 2/ or Two Independent Flight Director Systems

Equipment for Identification of Decision Height

Can be: (1) Radar altimeter, or (2) Inner Markers.

Missed Approach Attitude Guidance

Can be: (1) Attitude gyros with calibrated pitch markings, or (2) Flight director pitch command, or (3) Computed pitch command.

Auto Throttle System

Required all turbojets if operations based on dual flight directors. Also required any aircraft using split axis couplers if applicant can't show it does not significantly reduce pilot workload.

Rain Removal Equipment

1/ Single axis flight directors if basic glide slope information displayed on same instrument.

2/ Split axis acceptable.

3/ If improved failure warning system not provided for CAT I operations applicant must must establish flight crew procedures and duty assignment to provide immediate detection of essential instrument and equipment failures. Such procedures and assignments are required for Category II operations.

*Source: *FAA ADVISORY CIRCULAR 120-29*. Sept. 25, 1970

Figure 3.— Airborne Equipment Requirements
Category III*

Minimum Requirements

Two ILS Localizers and Glide Slope Receivers

Two Approved Radio (Radar) Altimeter Systems

Redundant Flight Control Systems

Can be:

- (1) Two (or possibly more) monitored autopilots, (making up an automatic, fail-operational system) one remaining operative after a failure.
- (2) Two monitored systems, each consisting of an integrated autopilot and flight director system with common flare computation, with one monitored system remaining operational after a failure.
- (3) Three autopilots, two remaining operative (to permit comparison and provide necessary hard-over protection) after a failure.
- (4) A single, monitored fail-passive automatic flight control system with flare computation and automatic flare and landing, plus an adequately failure-protected flight director system with dual displays (or dual flight director system) with flare computation, (independent of that used for the autopilot) supplied to the command bars.

Missed Approach Attitude Guidance

Can be:

- (a) Attitude gyro indicators with calibrated pitch attitude markings, or
- (b) Fixed or computed pitch command display, or
- (c) An automatic go-around system with either (a or b) above.

Auto Throttle Control System (Single)

Failure Detection and Warning Capability

*Source: *FAA ADVISORY CIRCULAR 120-28A*, Dec. 14, 1971

Category III operation capability emphasis is on redundancy applied to the automatic landing system, and on total system design using integrated displays. The Advisory Circular on Category III operation (ref. 36) also covers tight touchdown dispersion limits; adequate ILS beam quality; and instrument and related system fault survival. The first operational Category IIIa instrument landing

system was commissioned at Dulles International Airport in early 1972. The Category IIIa equipment at Dulles is known as the STAN-37/38 system, manufactured by Standard Telephones and Cables, Ltd. of Great Britain. It was made available to the FAA by the British Dept. of Trade and Industry on a two-year loan for evaluation with an option to buy (ref. 37). The Category IIIa ILS components are similar to Category II equipment, however, the localizer and glide slope must be capable of performing within more stringent tolerances. Category III equipment must provide improved signal accuracy and reliability.

Aircraft operators must satisfy criteria with respect to airport and ground facilities, airborne systems, training requirements and maintenance standards before Category II or Category IIIa minimums can be approved. Strong competitive financial advantages exist to persuade aircraft operators to seek Category II operation approval. The advantages of capability for Category IIIa operation are being seriously questioned by aircraft operators.

All-Weather Landing Systems

Much research and development effort is being invested in reaching the goal of all weather landings. All weather landings imply the integration of navigation, autopilot, and display necessary to execute landings in low visibility, low ceiling, crosswinds, storm activity, and poor runway taxi conditions. An all-weather landing system is also tied to provision for ground transport facilities to move passengers and cargo.

Microwave Landing System (MLS)

The MLS is a new landing system to be installed at airports with and without conventional ILS. The MLS is envisioned to eventually replace the ILS providing more accurate landing guidance signals at airports where terrain prohibits an accurate ILS approach.

Whereas present ILS systems basically provide a single approach path, MLS covers a broad area, increasing the number of available flight paths. The MLS is capable of providing continuous

distance information, eliminating the need for marker beacons. As in the ILS, ground stations transmit electromagnetic signals to the aircraft. The signals provide azimuth, elevation and range information which is displayed and fed into automatic flight control systems. The difference between the two systems is in signal wavelength. The microwave is an electromagnetic wave of extremely high frequency. The higher frequencies of MLS permit focusing energy in a narrow beam which reduces environmental influence, and scanning through very wide angles. Thus, the advantages of MLS are (ref. 38):

1. greater dependability;
2. noise abatement;
3. reduced delays;
4. low cost compatibility;
5. special use by V/STOL; and
6. common civil/military use.

There are several concepts being employed by manufacturers of MLS: the conventional scanning beam technique using mechanical or electronic rotation, and the Doppler scanning technique. These are described in the FAA document, "National Plan for Development of the Microwave Landing System" (ref. 39).

FAA National Plan for MLS

In July 1971, the DOT/FAA published its five-year National Plan for the development and implementation of a common civil/military MLS (ref. 39). The plan was prepared by a joint planning group drawn from the FAA, DOD and NASA, and based on the technical recommendations of the Radio Technical Commission for Aeronautics Special Committee 117 (RTCA SC117). The plan provides for two development programs: (1) an industry program to produce prototype equipment for flight test and evaluation; and (2) a series of government programs to support the industry program. The government programs will include validation efforts, investigation of subsystem concepts and techniques, and the application of the MLS to the needs of specific aircraft.

Interim MLS (I-MLS)

The FAA would like to discourage wide-spread acceptance and installation of the different microwave landing systems until a common system can be determined, thus eliminating the possibility of several different systems requiring differing ground facilities as well as differing airborne equipment. Potential contenders for the I-MLS include Tull Aviation and Thomson-CSF (the system, called Sydac, will be bid by Texas Instruments, which builds ILS systems under license to the French company, Thomson-CSF) which have a split-site design. The other contenders, Boeing Electronics, Singer-Kearfott and the AIL Division of Cutler-Hammer have a co-located design. Table 2 describes these systems.

AIL has developed and tested a series of microwave scanning beam systems including:

1. FLARESCAN – flare guidance for military,
2. Advanced Integrated Landing System (AILS) – an ultra-precision equipment to provide Category III service to major airports,
3. C-SCAN (AN/SPN-41) – low approach guidance to aircraft carriers,
4. C-SCAN (AN/TRN-28) – Category II low approach guidance to shore bases,
5. A-SCAN (U. S. Army Tactical Landing System) – transportable landing guidance for tactical helicopters, and
6. Tactical Instrument Landing System (TILS) – for the SAAB Viggen.

REGULATIONS

The primary regulating agencies for aircraft are the Federal Aviation Administration and the Civil Aeronautics Board. The government's regulatory effort is aided considerably by the effort of government/industry working groups such as Aeronautical Radio, Inc. (ARINC); the Radio Technical Commission for Aeronautics (RTCA); and the Society of Automotive Engineers, Inc. (SAE). International standards are developed by the International Civil Aviation Organization (ICAO) and promoted by international groups such as the International Air Transport Association (IATA).

TABLE 2.— MICROWAVE LANDING SYSTEMS*

Company	System	Freq.	Airborne Receiver	Azimuth Coverage	Glide Slope	Cost
AIL Division of Cutler-Hammer	Co-Scan	K _u band	20 Channels Independent not adaptable to existing ILS	±20° @ 10 n.mi.	0-15° selectable in aircraft	
Boeing ^[1]		C band	Converter adapts signals to existing ILS display	30° @ 18 SM	6° adjustable 2.5° to 5°	Ground unit \$40,000 Airborne \$4,000
Kearfott Division of Singer	TALAR	K _u band	1 Channel Independent 8.5 lb.	±30° @ 10 n.mi. ±55° @ 2 n.mi.	2-6° adjustable on ground	Ground unit (uninstalled) \$42,000, Airborne \$5,000
Tull Aviation		C band	Converter			Ground installed \$100,000
M.E.L. Equipment ^[2] of England	Madge-2			90° Approach 130° @ 16 n.mi.	2-25° pilot selectable	Ground \$30,000 Airborne \$1,250 Madge-3 computer \$30,000
Thomson-CSF of France		C band	Converter			

[1] "Boeing's microwave ILS" *Flight International*, 14 Sept. 1972.

[2] "New Microwave Guidance Unit Has Combat, VTOL Capabilities" *Aviation Week & Space Technology*, 6 Dec. 1971.

*Source: "Microwave Landing System" *Business & Commercial Aviation*, Oct. 1972.

Federal Air Regulations (FAR's)

The FAR's are contained in the Code of Federal Regulations (ref. 40) and published in the Federal Register and comprise 199 parts. Parts 23 and 25 specify requirements for *aircraft certification*, Part XX specifies requirements for powered lift aircraft certification, and Part 37 describes Technical Standard Orders (TSO's). Parts 121 and 135 specify requirements for *operation certification* of large aircraft operated by air carriers and commercial operators, and of small aircraft operated by air taxi and commercial operators respectively. Aircraft with a maximum gross takeoff weight of more than 12,500 lbs must be operated under the provisions of Part 121.

FAR Part 23

Part 23, Airworthiness Standards: Normal, Utility, and Acrobatic Category Airplanes, requires the following flight and navigation instruments:

- (1) airspeed indicator
- (2) altimeter
- (3) magnetic direction indicator

Part 23 specifies installation for:

- (1) airspeed indicating system
- (2) static pressure system
- (3) magnetic direction indicator
- (4) automatic pilot system
- (5) instruments using a power supply
- (6) flight director instrument

FAR Part 25

Part 25, Airworthiness Standards: Transport Category Airplanes, requires the following flight and navigation instruments:

- (1) free air temperature indicator
- (2) clock

- (3) direction indicator
- (4) dual airspeed indicator
- (5) dual altimeter
- (6) dual rate-of-climb indicator
- (7) dual gyroscopic rate-of-turn indicator combined with an integral slip-skid indicator (turn-and-bank) except that only a slip-skid indicator is required on large airplanes with a third attitude instrument system usable through flight attitudes of 360° pitch and roll and installed in accordance with FAR Part 121.
- (8) dual gyroscopic bank and pitch indicator (artificial horizon)
- (9) dual gyroscopic direction indicator
- (10) a speed warning device for turbine engine powered aircraft and for aircraft with V_{MO}/M_{MO} greater than $0.8 V_{DF}/M_{DF}$ or $0.8 V_D/M_D$.
- (11) dual machmeter for airplanes with compressibility limitations not otherwise indicated to the pilot by the airspeed indicating system.

Part 25 miscellaneous equipment required include:

(1) Two systems for two-way radio communications, with controls for each accessible from each pilot station, designed and installed so that failure of one system will not preclude operation of the other system. The use of a common antenna system is acceptable if adequate reliability is shown.

(2) Two systems for radio navigation, with controls for each accessible from each pilot station, designed and installed so that failure of one system will not preclude operation of the other system. The use of a common antenna system is acceptable if adequate reliability is shown.

Part 25 specifies regulations for control surfaces stability augmentation, and automatic and power operated systems, and specifies installation for:

- (1) airspeed indicating system
- (2) static pressure systems

- (3) magnetic heading indicator
- (4) automatic pilot system
- (5) instruments using a power supply
- (6) instrument systems
- (7) cockpit voice recorders
- (8) flight recorders

FAR Part XX

Part XX, Tentative Airworthiness Standards for Powered Lift Transport Category Aircraft, specifies powered lift aircraft certification requirements.

Flight and navigation equipment required are:

- 1. free air temperature indicator
- 2. clock
- 3. direction indicator
- 4. dual airspeed indicator
- 5. dual altimeter
- 6. dual rate-of-climb indicator
- 7. dual gyroscopic rate-of-turn indicator combined with an integral slip-skid indicator (turn and bank indicator) except that only a slip-skid indicator is required on large aircraft with a third attitude instrument system installed in accordance with FAR Part 121
- 8. dual gyroscopic bank and pitch indicator (artificial horizon)
- 9. dual gyroscopic direction indicator
- 10. speed warning device
- 11. dual machmeter (for aircraft where airspeed indicator not sufficient)

Miscellaneous equipment required are:

- 1. dual two-way radio communications
- 2. dual radio navigation.

Like Parts 23 and 25, Part XX specifies instrument installation including arrangement and visibility for the instruments most effectively indicating attitude, airspeed, altitude, and direction of flight as well as:

- (1) speed indicating system
- (2) static air vent and pressure altimeter systems
- (3) magnetic direction indicator
- (4) automatic pilot system
- (5) instruments using a power supply
- (6) systems that operate the instruments

FAR Part 37

Part 37, Technical Standard Order Authorizations, describes Technical Standard Orders (TSO's) containing minimum performance and quality control standards for specified materials, parts, or appliances used on civil aircraft. Avionics equipment for which there is a TSO include:

- (1) airspeed indicator (pitot static) TSO-C2b
- (2) turn and slip indicator TSO-C3b
- (3) bank and pitch instruments (indicating gyro-stabilized type) (gyroscopic horizon, attitude gyro) TSO-C4c
- (4) direction instrument, non-magnetic, gyro-stabilized type (directional gyro) TSO-C5c
- (5) direction instrument, magnetic (gyro-stabilized type) TSO-C6c
- (6) direction instrument, magnetic non-stabilized type (magnetic compass) TSO-C7c
- (7) rate-of-climb indicator, pressure actuated (vertical speed indicator) TSO-C8b
- (8) automatic pilot TSO-C9c
- (9) altimeter, pressure actuated, sensitive type TSO-C10b
- (10) airborne radio marker receiver equipment operating on 75 Mc (for air carrier aircraft) TSO-C35c
- (11) VOR radio receiving equipment operating within the radio-frequency range of 108-118 megacycles (for air carrier aircraft) TSO-C40a
- (12) airborne radio receiving and direction finding equipment operating within the radio frequency range of 200-415 kilocycles (for air carrier aircraft) TSO-C41b

- (13) aircraft audio and interphone amplifiers TSO-C50b
- (14) aircraft flight recorder TSO-C51a
- (15) flight directors TSO-C52a
- (16) stall warning instruments TSO-C54
- (17) aircraft headsets and speakers (for air carrier aircraft) TSO-C57
- (18) aircraft microphones (for air carrier aircraft) TSO-C58
- (19) High Frequency (HF) radio communication receiving equipment operating within the radio frequency range of 1.5 to 30 megacycles TSO-C32c
- (20) airborne ILS glide slope receiving equipment (for air carrier aircraft) TSO-C34b
- (21) airborne ILS localizer receiving equipment operating within the radio-frequency range of 108-112 megacycles TSO-C36b
- (22) VHF radio communications transmitting equipment operating within the radio-frequency range of 118-136 megacycles TSO-C37b
- (23) VHF radio communications receiving equipment operating within the radio-frequency range of 118-136 megacycles TSO-C38b
- (24) airborne selective calling equipment (for air carrier aircraft) TSO-C59
- (25) airborne Loran A receiving equipment operating within the radio-frequency range of 1800-2000 kilocycles (for air carrier aircraft) TSO-C60
- (26) portable aircraft emergency communications equipment (for air carrier aircraft) TSO-C61a
- (27) airborne weather radar equipment operating within the radio-frequency bands of 5,350 to 5,470 Mc and 9,300 to 9,500 Mc TSO-C63a
- (28) airborne doppler radar ground speed and/or drift angle measuring equipment (for air carrier aircraft) TSO-C65
- (29) airborne distance measuring equipment (air carrier aircraft) TSO-C66a
- (30) airborne radar altimeter equipment (for air carrier aircraft) TSO-C67
- (31) airborne automatic dead reckoning computer equipment utilizing aircraft heading and doppler-obtained ground speed and drift angle data (for air carrier aircraft) TSO-C68
- (32) airborne ATC transponder equipment TSO-C74a
- (33) cockpit voice recorder TSO-C84
- (34) airborne Low-Range Radio Altimeter TSO-C87

- (35) automatic pressure altitude digitizer equipment TSO-C88
- (36) emergency locator transmitter TSO-C91

FAR Part 121

Operation under provisions of Part 121, Certification and Operations: Domestic, Flag, and Supplemental Air carriers and Commercial Operators of Large Aircraft, requires the following avionics in operable condition for takeoff:

- (1) airspeed indicating system with heated pitot tube
- (2) sensitive altimeter
- (3) sweep-second hand clock
- (4) free-air temperature indicator
- (5) gyroscopic bank and pitch indicator (artificial horizon)
- (6) gyroscopic rate-of-turn indicator combined with an integral slip-skid indicator (turn-and-bank indicator) except that only a slip-skid indicator is required when a third attitude instrument system usable through flight attitudes of 360° pitch and roll is installed in accordance with paragraph (10)
- (7) gyroscopic direction indicator (directional gyro or equivalent)
- (8) magnetic compass
- (9) vertical speed indicator (rate-of-climb indicator)
- (10) after August 5, 1971, on large turbojet powered airplanes, in addition to two gyroscopic bank-and-pitch indicators (artificial horizons) for use at the pilot stations, a third such instrument that is powered from an independent source, operates independently of any other attitude indicating system and is operative without selection for 30 minutes after total failure of the electrical generating system.
- (11) cockpit voice recorder

For operation at night, or under IFR or over-the-top conditions the airplane must be equipped with the following avionics in addition to those above:

- (1) airspeed indicating system with heated pitot tube
- (2) sensitive altimeter

For extended overwater operations, a survival type emergency locator transmitter is required. For operation of a large airplane that is certificated for operations above 25,000 feet altitude or is turbine engine powered a flight recorder is required; and after March 18, 1974, each flight recorder must have an approved device to assist in locating that recorder under water.

Radio equipment requirements:

for VFR pilotage:

- (1) communication with ground facility
- (2) communication with ATC facility
- (3) receive meteorological information by either of two independent systems (one of which may be used to comply with (1) and (2))

for VFR pilotage at night:

in addition, need radio navigation equipment applicable to route flown except that marker beacon receiver or ILS receiver is not required

for VFR not pilotage or IFR over-the-top:

- (a) (1), (2), (3), above and equipment to receive by either of two independent systems, radio navigation signals from primary enroute and approach navigational facilities intended to be used. However only one MB receiver and one ILS receiver need be provided. Equipment provided to receive signals enroute may be used to receive signals on approach, if it is capable of receiving both signals.
- (b) only one LF radio range or ADF receiver need be installed if equipped with two VOR receivers
- (c) whenever VOR navigation receivers are required by (a) or (b), at least one DME

for Extended Over-water operation:

same as for IFR over-the-top plus an independent system that satisfies (1), (2), (3)

for Operation over uninhabited terrain areas:

survival type emergency locator transmitter after Oct. 21, 1972

In addition, airborne weather radar must be operating for IFR or night VFR flight if weather conditions that can be detected with airborne weather radar may reasonably be expected along the route.

FAR Part 135

Part 135, Air Taxi Operators and Commercial Operators of Small Aircraft

General equipment requirements:

- (1) sensitive altimeter

Passengers at night or VFR over-the-top conditions:

- (1) a gyroscopic rate-of-turn indicator combined with slip-skid indicator;
- (2) a gyroscopic bank-and-pitch indicator (artificial horizon);
- (3) a gyroscopic direction indicator

Passengers under IFR:

- (1) a vertical speed indicator
- (2) a free-air temperature indicator
- (3) a heated pitot tube for each airspeed indicator
- (4) a power failure warning device or vacuum indicator
- (5) an alternate source of static pressure

Radio and navigation for VFR at night, over-the-top, or in a control zone:

- (1) two-way radio communications equipment
- (2) radio navigation equipment appropriate to ground aids being used

Radio and navigation for extended overwater or IFR operation:

- (1) a transmitter
- (2) two microphones
- (3) two headsets or one headset and one speaker
- (4) a marker beacon receiver
- (5) two independent receivers for navigation
- (6) two independent receivers for communications
- (7) for extended overwater operations only, an additional transmitter, however a receiver that can receive both navigation and communications may be used in place of a separate navigation and communication

Figure 4 indicates recent avionics regulations and proposed regulations.

ARINC Characteristics

ARINC, Aeronautical Radio, Inc. is a corporation whose stockholders are mainly U. S. airlines and in addition, air transport companies, aircraft manufacturers, and foreign airlines. Among its activities are operation of aeronautical land radio stations, allocation of frequencies, standardization of airborne communications and electronics systems, and the exchange of technical information. ARINC sponsors the Airlines Communications Administrative Council (ALCAC) whose function is to establish the industry common interest communications policies. One of the ALCAC standing committees is the Airlines Electronic Engineering Committee (AEEC), which formulates standards for electronic equipment and systems for the airlines in the form of Equipment Characteristics. An ARINC Equipment Characteristic indicates to prospective manufacturers the requisites of new equipment as determined by the airline technical people, and channels new equipment design in the direction of maximum possible standardization without restricting engineering initiative. However, the ARINC Equipment Characteristic does not constitute a requirement for such equipment, or commit any airline to purchase such equipment. Table 3 lists the ARINC Characteristics which cover items described in this paper.

EQUIPMENT	REG OR PROPOSED REG	SYNOPSIS
TSO'd Transponder	To be issued May or June.	Would set up 4 classes of transponders (see diagram, p. 57) and create a companion TSO (C-74c) to the present transponder TSO (C-74b). New TSO is earmarked for FAR 91 aircraft. Rule, essentially, would require any transponder installed after a date still to be set in a FAR 91 aircraft to meet either C-74b or c. After later date, not yet fixed, transponders in <i>all</i> FAR 91 aircraft would have to meet one of these TSO's. (Rule would also require transponders in FAR 121, 123, 127 and 135 aircraft to meet C-74b or class 1A or 1B of C-74c.)
Emergency Locator Transmitters	Fed. law of Dec. 29, 1970.	New aircraft delivered after Dec. 29, 1971 must have approved ELT; all others by Dec. 29, 1973. Essentially, approval means meeting specs of TSO-91. Jet transports, local training aircraft, ag aircraft and certain scheduled operators are excluded.
200-channel VHF Nav (VOR/LOC) Receiver	FAA AC 170-12 Oct. 7, 1970. No firm date set for when this equipment will be needed. Believed it may be in 1973.	Not mandatory but 200-channel nav receivers will be needed for full use of ATC system, esp in high density terminals. (Problem: FAA must first install gnd stations. Harmonic interference among stations could delay program.)
200-channel DME	Essentially same remarks as above.	Essentially same remarks as above except for item in parentheses.
40-channel glide slope	Essentially same remarks as above.	Essentially same remarks as above except for item in parentheses.
Altitude alerter	AC 91-22 July 1, 1969. Required as of Feb. 29, 1972.	Mandatory only for Jet-powered aircraft (air-carrier and general aviation).

Figure 4.— Recent avionics regulations and proposed regulations.*

*Source: *Business & Commercial Aviation*, April 1972

EQUIPMENT	REG OR PROPOSED REG	SYNOPSIS
Altitude Reporting Altimeter (i.e. encoding altimeter)	New NPRM in process: previous one (69-9) has been superseded.	Would be required for any aircraft in post cont airspace, in TCA's and, possibly, in cont airspace above a certain altitude. Depends on installation of ARTS III ground stations (all of which are due to be completed in 1974).
720-channel VHF comm transceiver (i.e. with 25-kc wide channels)	Preliminary notice of proposal (not an NPRM) sent out by FAA in Feb. '72.	FAA proposes to start integration of the 25 kc comm channels into the National Airspace System about Jan. 1976 beginning with selected high altitude enroute sectors.
Avionics meeting Minimum Operating Characteristics	MOC's for each essential type of avionics equipment either have been written or are being written. Each will be introduced via NPRM procedure.	Avionics equipment that meets either the issued MOC or corresponding TSO will probably be required by all aircraft using the airways and controlled airspace.
Proximity Warning Indicator	Senate bill calling for PWI for all aircraft 12,500 lb. or less has been shelved.	No PWI has been sanctioned by FAA. Lack of an acceptable PWI as well as definition of what one is to do has created considerable uncertainty within FAA on how to proceed.
Collision Avoidance System	Same Senate bill as above would have required CAS for all aircraft 12,500 lb. As noted, this bill has been shelved.	No CAS has been sanctioned by FAA which must first determine if such equipment is necessary.

Figure 4.— Concluded.

TABLE 3.— ARINC CHARACTERISTICS EFFECTIVE 6/19/72

NUMBER	SUBJECT	ISSUED	LATEST PRINTING
<i>Rpt. 201</i>	AEEC Data Link Project Newsletters Volume 1 — Includes Newsletters 1 through 125, June 1968 to August 1970	9/15/70	9/15/70
<i>Rpt. 201</i>	AEEC Data Link Project Newsletters Volume 2 — Includes Newsletters 126 through 148, September 1970 to December 1971	1/31/72	1/31/72
<i>Rpt. 202</i>	RNAV Project Newsletters — Includes Newsletters 1 through 41, May 1969 to December 1970	4/15/71	4/15/71
<i>Rpt. 203</i>	ATE Project Newsletters, Volume 1 — Includes Newsletters 1 through 29, December 1966 to September 1968	10/1/71	10/1/71
<i>Rpt. 203</i>	ATE Project Newsletters, Volume 2 — Includes Newsletters 30 through 48 continuing September 1968 through September 1971	10/1/71	10/1/71
<i>Rpt. 299</i>	AEEC Letter Index (1951 thru November 1959)	12/1/59	9/30/63
<i>Rpt. 299-1</i>	AEEC Letter Index (1 December 1959 thru 10 October 1968)	11/1/68	11/10/70
<i>Rpt. 299-2</i>	AEEC Letter Index (15 October 1968 thru December 1970)	5/16/69	12/31/70
<i>Rpt. 304*</i>	Electronic Installation Guidance Material	8/1/53	8/1/53
<i>Rpt. 306*</i>	Guidance for Designers of Aircraft Electronic Installations (Bound with Supplement 1)	9/1/55	8/15/66
<i>Rpt. 307*</i>	AIDS Wire Bundle Provisions (Standardized Interim Space and Wire Bundle Provisions for Future Implementation of AIDS Equipment)	2/9/68	2/9/68
<i>Rpt. 308</i>	RNAV Wire Bundle Provisions (Standardized Interim Space and Wire Bundle Provisions for Future Implementation of RNAV Equipment)	7/15/70	7/15/70

TABLE 3.— ARINC CHARACTERISTICS EFFECTIVE 6/19/72 — Continued

NUMBER	SUBJECT	ISSUED	LATEST PRINTING
<i>Spec. 401*</i>	Crystal Unit Specification	11/20/52	11/28/58
<i>Rpt. 402A*</i>	Preferred List of Special Quality Tubes	7/8/55	MAR /60
<i>Rpt. 403*</i>	Guidance for Designers of Airborne Electronic Equipment (Updated by and should be used in conjunction with Report 414)	9/1/55	9/1/55
<i>Spec. 404</i>	Air Transport Equipment Cases and Racking (Bound with Supplements 1 thru 8) Available Separately to Update ARINC 404 Documents: Supplement 8 (AEEC letter 71-1-14)	5/1/56 12/8/70	12/31/70 12/8/70
<i>Rpt. 405*</i>	ADF Antenna Requirement for the Commercial Airlines	11/10/55	11/10/55
<i>Rpt. 406A</i>	Airborne Electronic Equipment Standardized Interconnections and Index Pin Codes (Pinformation Report)	10/12/56	4/1/66
<i>Rpt. 407</i> (Combined Issue)	ARINC Synchro System Manual (New Combined Issue of Report 407 and 407-1, "ARINC Synchro Signal Practices")	11/19/50	3/17/66
<i>Spec. 408</i>	Air Transport Indicator Cases and Mounting	6/10/60	10/1/65
<i>Spec 409A*</i>	Selection and Application of Semiconductor Devices	11/1/62	11/1/62
<i>Spec. 410</i>	Mark 2 Standard Frequency Selection System (Bound with Supplement 1)	10/1/61	4/30/65
<i>Rpt. 411*</i>	Investigation of Electron Tube Reliability in Commercial Airline Application (Final report on Controlled Test 13)	3/15/61	3/15/61
<i>Project Paper 412</i>	Audio Systems (ARINC Report 412) — Approved by AEEC October 15, 1964, approved by ALCAC Feb. 2, 1965, circulated in AEEC Letter No. 64-2-47 dated 9/30/64 (not published in Gray Cover)	9/30/64	9/30/64

TABLE 3.— ARINC CHARACTERISTICS EFFECTIVE 6/19/72 — Continued

NUMBER	SUBJECT	ISSUED	LATEST PRINTING
<i>Spec. 413</i>	Guidance for Aircraft Electrical Power Utilization and Transient Protection	5/1/67	5/1/67
<i>Rpt. 414</i>	General Guidance for Equipment and Installation Designers	9/3/68	9/3/68
<i>Rpt. 415-2</i>	Operational and Technical Guidelines on Failure Warning and Functional Test (Also bears number: ATA Report No. 112-2)	2/15/66	1/10/68
<i>Rpt. 416-5</i>	Abbreviated Test Language for Avionics Systems (ATLAS)	6/1/69	2/21/72
	Available Separately to Update 416-3 Documents:		
	Supplement 4 (AEEC Letter N 72-024/ATE-54)	2/22/72	2/22/72
	Supplement 5 (AEEC Letter N 72-025/ATE-55)	2/22/72	2/22/72
<i>Rpt. 417</i>	Design Guidance Air Transport Automatic Flight Control	4/9/71	4/9/71
<i>Rpt. 418</i>	A Guide to ATLAS for Test Specification Writers	5/15/69	5/15/69
<i>Rpt. 420</i>	Standby Attitude Indicator (Bound with Supplement 1)	7/15/70	1/11/71
	Available Separately to Update ARINC 420 Documents:		
	Supplement 1 (AEEC Letter 71-1-12)	12/2/70	12/2/70
<i>Rpt. 421</i>	Guidance for Standard Subdivision of ATA Spec 100 Numbering System for Avionics	10/6/71	10/6/71
<i>Rpt. 422</i>	Guidance for Modification Status Indicators and Avionics Service Bulletins	2/29/72	2/29/72
<i>Char. 519*</i>	Airborne Glide Slope Receiving System	3/8/50	3/7/58

TABLE 3.— ARINC CHARACTERISTICS EFFECTIVE 6/19/72 — Continued

NUMBER	SUBJECT	ISSUED	LATEST PRINTING
<i>Char. 520A*</i>	Airborne VHF Communications System (Bound with Supplement 1)	6/20/54	3/24/58
<i>Char. 521D*</i>	Airborne Distance Measuring Equipment (DME) (Bound with Supplement 1) Available Separately to Update ARINC 521D Documents: Supplement 2 (AEEC Letter 71-116/DME-20)	11/1/63 9/9/71	1/21/65 9/9/71
<i>Chars. 522 thru 527</i> (Contained in single document)	Airborne HF Communications Characteristics: (522: Transmitters; 523: Transmitter Power Unit; 524: Selectors; 525: Antenna Tuning Unit; 526: 114-240 Channel Receiver; 527: Multi-Frequency Receivers)	3/21/52	11/29/62
<i>Char. 528*</i>	Airborne Tape Reproducer Characteristic (Revised 9/10/52)	1/10/52	9/10/52
<i>Char. 529*</i>	5.7 cm Weather Penetration Airborne Radar (Bound with Supplements 2 and 3)	6/28/54	1/22/64
<i>Char. 530A*</i>	Airborne ADF System (Bound with Supplement 1)	4/2/56	3/24/58
<i>Char. 531*</i>	Airborne Selective Calling System (Bound with Supplements 1 and 2)	6/28/54	1/3/61
<i>Char. 532D*</i>	Air Traffic Control Transponder (Bound with Supplements 1 thru 3)	3/1/62	2/15/66
<i>Char. 533A</i>	Airborne HF SSB/AM System	3/1/66	3/1/66
<i>Char. 534*</i>	VHF Emergency Transceiver	3/25/57	3/25/57
<i>Char. 535A</i>	Lightweight Headset and Boom Microphone	3/3/72	3/3/72
<i>Char. 537*</i>	High Range Pulse Altimeter	11/15/57	11/15/57

TABLE 3.— ARINC CHARACTERISTICS EFFECTIVE 6/19/72 — Continued

NUMBER	SUBJECT	ISSUED	LATEST PRINTING
<i>Char. 538A</i>	Hand-Held Microphone	3/3/72	3/3/72
<i>Char. 539A</i>	Airborne 400 HZ AC Tape Reproducer (Bound with Supplement 1)	10/1/68	10/1/68
<i>Char. 540-2*</i>	Airborne Doppler Radar (Document revised to incorporate Supplements 1 and 2. Supplement 3 bound in document)	6/1/58	3/25/62
<i>Char. 541*</i>	Airborne Magnetic Flight Data Recorder	9/10/58	9/10/58
<i>Char. 542</i>	Airborne Oscillographic Flight Data Recorder (Bound with Supplement 1 and 2)	9/10/58	6/1/66
<i>Char. 543*</i>	Airborne Doppler Radar Mark 1 Computer (Bound with Supplement 1)	2/6/59	10/1/65
<i>Char. 544A</i>	Airborne Announcement Tape Reproducer	10/1/68	10/1/68
<i>Char. 545*</i>	Subsonic Air Data Computer System (Bound with Supplement 1)	10/1/61	10/26/66
<i>Char. 545A</i>	Mark 1 1/2 Subsonic Air Data System (ADS)	2/3/69	2/3/69
<i>Char. 546</i>	Airborne VHF Communications Transceiver System	10/1/61	10/1/61
<i>Char. 547</i>	Airborne VHF Navigation Receiver (Bound with Supplement 1)	10/1/61	2/15/68
<i>Char. 548*</i>	Altitude Encoder	3/1/62	12/21/66
<i>Char. 549*</i>	Altitude Computer System	3/1/62	3/1/62
<i>Char. 550*</i>	Airborne ADF System — Mark 2 (Bound with Supplement 1)	3/1/62	12/1/64

TABLE 3.— ARINC CHARACTERISTICS EFFECTIVE 6/19/72 — Continued

NUMBER	SUBJECT	ISSUED	LATEST PRINTING
<i>Char. 551</i>	Airborne Glide Slope Receiver — Mark 2	3/1/62	3/1/62
<i>Char. 552A</i>	Radio Altimeter (Bound with all Supplements thru 4)	3/15/72	3/15/72
	<i>Special Note:</i> Draft Revised Supplement No. 1, "Form Factor and Interwiring Changes" to Characteristic No. 552 dated: 8-1-65 (This Supplement, although approved by the Industry, is still in draft form. This revised Supplement No. 1 was circulated in AEEC Letter No. 65-2-30 dated August 4, 1965 and is bound with the Char. 552 Document).		
	Supplement 5 (AEEC Letter 72-033/RALT-00)	3/15/72	3/15/72
<i>Char. 554</i>	Airborne Engine Vibration Pickup	6/15/63	6/15/63
<i>Char. 555</i>	Airborne Engine Vibration Monitor	1/10/64	1/10/64
<i>Char. 557</i>	Airborne Voice Recoder (Bound with Supplement 1)	1/10/64	1/10/64
<i>Char. 558</i>	Automatic Throttle System	7/1/64	7/1/64
<i>Char. 559</i>	Mark 2 Airborne HF SSB/AM System	8/6/71	8/6/71
<i>Char. 560</i>	Airborne Passenger Address Amplifier (PA AMP)	8/31/66	8/31/66
<i>Char. 561-7</i>	Air Transport Inertial Navigation System (INS)	6/1/67	8/30/71
	Available Separately to Update ARINC 561-6 documents:		
	Supplement 7 (AEEC Letter 71-105/INS-89)	8/30/71	8/30/71
<i>Char. 562</i>	Supplement 1 to Draft Characteristic 562 (AEEC Letter 71-1-15)	12/7/70	12/7/70
<i>Char. 563-1</i>	Aircraft Integrated Data System (AIDS)	7/8/71	7/8/71
	Available Separately to Update ARINC 563 Documents:		
	Supplement 1 (AEEC Letter 71-088/AIDS-94)	7/8/71	7/8/71

TABLE 3.— ARINC CHARACTERISTICS EFFECTIVE 6/19/72 — Continued

NUMBER	SUBJECT	ISSUED	LATEST PRINTING
<i>Char. 564-7</i>	Airborne Weather Radar Available Separately to Update ARINC 564 Documents: Supplement 7 (AEEC Letter 71-017/WXR-50)	11/1/67 4/30/71	4/30/71 4/30/71
<i>Char. 565</i>	Mark 2 Subsonic Air Data System	2/15/68	2/15/68
<i>Char. 566</i>	Airborne VHF Communications Transceiver and Mark 1 VHF SATCOM Systems	10/17/68	10/17/68
<i>Char. 568-3</i>	Mark 3 Airborne Distance Measuring Equipment (Bound with Supplement 1) Available Separately to Update ARINC 568 Documents: Supplements 2 and 3 (AEEC Letter 71-042/DME-19)	2/9/68 6/1/71	6/1/71 6/1/71
<i>Char. 569</i>	Heading and Attitude Sensor (HAS)	10/15/69	10/15/69
<i>Char. 570</i>	Mark 3 Airborne ADF System (Bound with Supplements 1 thru 3)	9/18/68	3/22/71
<i>Char. 571-1</i>	Inertial Sensor System (ISS) Available Separately to Update ARINC 571 documents: Supplement 1 (AEEC Letter 71-109/INS-90)	8/10/71 8/30/71	8/30/71 8/30/71
<i>Char. 572-1</i>	Mark 2 Air Traffic Control Transponder	2/5/71	2/5/71
<i>Char. 573-5</i>	Aircraft Integrated Data System (AIDS) — Mark 2	5/26/71	5/26/71
<i>Char. 575-3</i>	Mark 3 Sub-Sonic Air Data System (Digital) DADS Available Separately to Update ARINC 575 Documents: Supplement 3 (AEEC Letter 71-090/ADS-51)	2/10/69 7/15/71	7/15/71 7/15/71

TABLE 3.— ARINC CHARACTERISTICS EFFECTIVE 6/19/72 — Continued

NUMBER	SUBJECT	ISSUED	LATEST PRINTING
<i>Char. 576</i>	Mark 4 Sub-Sonic Air Data System (All Digital Outputs) DADS	2/10/69	2/10/69
<i>Char. 577</i>	Audible Warning System	7/1/70	7/1/70
	Available Separately to Update ARINC 577 Documents:		
	Supplement 1 (AEEC Letter 71-115/AWS-00)	9/2/71	9/2/71
<i>Char. 578-2</i>	Airborne ILS Receiver	9/8/71	9/8/71
	Available Separately to Update ARINC 578-1 Documents:		
	Supplement 2 (AEEC Letter 71-119/ILS-06)	9/8/71	9/8/71
	Supplement 3 (AEEC Letter 72-066/ILS-10)	5/26/72	5/26/72
<i>Char. 579-1</i>	Airborne VOR Receiver	2/5/71	2/5/71
<i>Char. 581</i>	Mark 1 Area Navigation System	6/30/70	6/30/70
<i>Char. 582-2</i>	Mark 2 Area Navigation System	8/26/71	8/26/71
	Available Separately to Update ARINC 582-1 Documents:		
	Supplement 2 (AEEC Letter 71-110/RNAV-56)	8/30/71	8/30/71
	Supplement 3 (AEEC Letter 72-068/RNAV-68)	5/31/72	5/31/72
<i>Char. 583</i>	Mark 13 Area Navigation System	5/30/72	5/30/72
	Part 1 — System Interwiring and Navigation Computer Unit Racking Standards		
<i>Char. 585</i>	Electronic Chronometer System	6/16/72	6/16/72
<i>Char. 587-2</i>	Air Transport Time/Frequency Collision Avoidance System	9/20/71	9/20/71
	Available Separately to Update ARINC 587 Documents:		
	Supplement 2 (AEEC Letter 71-123/CAS-18)	9/27/71	9/27/71
	Supplement 3 (AEEC Letter 72-067/CAS-26)	5/26/72	5/26/72

TABLE 3.— ARINC CHARACTERISTICS EFFECTIVE 6/19/72 — Concluded

NUMBER	SUBJECT	ISSUED	LATEST PRINTING
<i>Char. 590</i>	Limited Level 1 Time/Frequency Collision Avoidance System	5/26/72	5/26/72
	ARINC Radio Communications Calculator — The ARINC Radio Communications Calculator has been designed to provide rapid and reasonably accurate solutions to problems encountered in the design and operation of Air/Ground VHF Communication system. Included with the calculator is a 55-page pocket size booklet which explains the design philosophy and use of the calculator with practical examples.		
	The Air Ground System Circa 1970's — Data Link -- This publication describes an Advanced Air-Ground Communications System envisioned for implementation in the 1970 decade using digital communication techniques.	6/20/69	6/20/69

Minimum Operational Characteristics (MOC's)

The Radio Technical Commission for Aeronautics (RTCA) is an association of aeronautical organizations of the United States from both government and industry. RTCA seeks technical solutions to problems involving aeronautical electronics, and makes recommendations to all organizations concerned. RTCA established Special Committee 116 to develop minimum operational characteristics (MOC's) for airborne systems. The MOC for each major airborne system element describes the basic system element, the minimum operational characteristics of the system element, and provides for demonstration of compliance by the equipment manufacturer's certification and statement of limitations; or by an approved Minimum Performance Standard such as a TSO, SAE Aeronautical Standard, or an RTCA Minimum Performance Standard; or by other methods of demonstrating capability (ref. 23).

ICAO Standards

The International Civil Aviation Organization (ICAO) has established international standards for VOR, ILS, and DME systems, and for approach lighting systems.

International Air Transport Association (IATA)

The technical committee of the (IATA) has assumed the responsibility to carefully examine new airborne systems and new techniques in order to insure that prior to their adoption for international application a definite and acceptable cost/benefit ratio exists (ref. 41). The IATA is also looking into: the European Space Research Organization (ESRO) and the U.S. FAA plans to introduce satellite communication utilizing the L-Band with full cost to be recovered from users; the International Civil Aviation Organization (ICAO) regional plans as they relate to IATA member's requirements. IATA is hopeful of reducing the direct operating cost of member airlines through a reduction in navigational aids, and in the number of ATC and meteorological centers and associated communications facilities; the planning of airports and terminal buildings; presenting governments with guidance and advice; and the relationship of aviation to the environment, strongly supporting the role of ICAO. IATA has authorized the establishment of the IATA Environmental Protection Advisory Committee.

TRENDS

The preceding description of present day avionics equipment easily divides into the areas of communication, navigation, flight control, and instrumentation. The widebody jets, DC-10 and L1011, began a new era of integrated systems in which navigation and flight control functions are so interrelated that they cannot be discussed separately. The trend toward an integrated systems design has led to some standardization and modularization. However the concept of an integrated avionics system with a computer architecture designed to perform the present functions of communication, navigation, flight control, and instrumentation automatically has not been realized. This concept is being explored for military (U.S.A.F. Digital Avionics Information System) and space applications and will probably be adopted for transport avionics in the future.

The next generation transport aircraft may incorporate numerous advances in avionics systems integration. For example, a change from wire-bundles to digital multiplexing systems will accommodate changes in avionic subsystems without the time and expense of rewiring the aircraft. This eliminates the weight, cost and complexity of large wire bundles, and the reliability problems of hundreds of electrical connections.

Reliability and Redundancy

Integration of navigation and flight control systems will be necessary for all-weather landing for all new types of civil aircraft including supersonic transport and V/STOL. The use of automatic flight controls during critical flight phases requires a high degree of confidence in the operation of the system. Currently this requires that system reliability be increased as much as possible, and in addition, some type of redundancy must be employed. Redundancy may be *active*, all channels operating and contributing to the control function, or *standby*, all channels operating, but only one of them contributes to the control function. The degree of redundancy, whether, two, three, or more channels, is a function of the reliability requirement. A *fail-passive* requirement means that the system will fail safely in the event of a single failure; a *fail-operational* requirement means that

the system will continue to operate after a single failure with no degradation and will fail safely in the event of a second failure (ref. 11, p. 516).

There are two means of detecting failures in channels: *in-line* monitoring where an individual channel or portion of a channel is tested to detect failure; or, *comparison* monitoring where corresponding signals in identical channels or portions thereof are compared.

"Integral" redundancy is a technique developed where elements are connected to allow multiple paths for the control signal, so that the failure of a component does not seriously degrade performance (ref. 42). The use of a logic test to reduce the chance of failure is called *voting*. The voter can supply a signal which agrees with at least two of the input signals in a triple channel system. An alternate version of the voter can select a signal having an intermediate amplitude among the three inputs, thereby capable of rejecting null failures, hardovers, or degraded signals due to open or short circuits (ref. 42).

Various technological events in the area of reliability are desirable and feasible, such as self-repair equipment for airborne systems, digital electronics, and redundant logic switching theory permitting uninterrupted performance of systems during small scale failures (ref. 43). Major reliability improvements will result from greater ability at low cost to control environment because of ultra-low-power, small volume electronics and extremely efficient heat exchangers.

Techniques are being developed to predict the reliability of man/machine relationships. Cockpits are becoming standardized so that a pilot can fly a variety of aircraft with only nominal additional training. Avionics systems are being designed with logic that detects errors in human operations, that senses and refuses to pass illogical operations, and advises the human to correct his mistake immediately. New optical displays are being introduced which will increase human operator reliability and accuracy of response to rapidly changing multiple inputs (such as in-flight radar monitors, FAA traffic controllers). Techniques are being developed for accelerated testing and non-destructive testing (ref. 43).

Maintenance

Of prime importance to the customer is the cost of maintenance since the cost of ownership of avionics equipment includes not only the acquisition cost, but the maintenance cost of such equipment. Overhaul frequencies (approximately every 9,000 to 16,000 hours) are set by a FAA maintenance review board and apply to the airframe only. Between overhaul times maintenance checks are scheduled (approximately every 350 to 500 hours). This check is done at the maintenance base and/or at service stations, preferably overnight. Some airlines pull out avionics equipment for periodic inspection and preventive maintenance. Some prefer to pull equipment on a maintenance demand basis (approximately 95% of non-airframe equipment is handled this way). As discussed in the reliability section, the trend is to design into the system means of making continuous checks on its behavior, with panel displays for failure indication and aircraft flight recorders which record numerous avionic performance parameters.

Automatic Test Equipment (ATE)

Maintaining avionics equipment formerly required many maintenance hours and a large group of supporting test equipment. Much of the maintenance is now accomplished using automatic test equipment (ATE) consisting of the following: (1) control by a general purpose digital computer; (2) numerous functionally independent test instruments connected in microseconds into various test configurations by means of a digital control system; (3) an interconnecting device consisting of an electro-mechanical interface to permit connection of the avionics unit under test (UUT) to the test station; and (4) a test program prepared in the test language used by the ATE.

United Air Lines, at its San Francisco International Airport maintenance base, uses ATE built by Honeywell, Inc. to test its air data systems and flight control systems (ref. 31). ATE has reduced the test time for the Boeing 747 auto-stabilizer from 4 hours to 30 minutes. The test language used is one provided by Honeywell called ELAN, which is a modification of Abbreviated Test Language for Avionic Systems (ATLAS). ATLAS was developed under the sponsorship of the Airlines Electronic Engineering Committee (AEEC) of ARINC to provide for exchange of test requirements

between airline avionic equipment suppliers and airline engineering and maintenance staff (ref. 44). The ATLAS language is defined by ARINC Specification 416. United does not use ATE for other avionics equipment because of software problems.

Martin Marietta's Martron Systems, Littleton, Colo. entered the ATE field for airlines avionics in 1970, having developed their expertise in ATE for defense and space programs.(ref. 45). Airlines using Martron equipment include Northwest Airlines, Eastern Airlines, National and Delta; also Finnair, Transportes Aeros Portugueses (TPA), Engins Matra and Dassault. Martron purchases standard power supplies and uses a Honeywell 316 mini-computer. The Martron 1200 is designed to test VHF communications subsystems, DME, and radar. The Martron 1200 can test each line replaceable unit of AFCS, stall computer, magnetic compass coupler, air data computer, and INS. To test pneumatic devices and inertial systems requires the purchase of separate stations for each function, if either is wanted. Each adds \$50,000--\$70,000 to the basic system price of \$200,000.

FUTURE AVIONICS REQUIREMENT

The future avionics complement of transport aircraft must be compatible with the FAA's National Aviation System Plan. The aircraft must be able to operate within the air traffic control environment that will exist in the 1980's. Plans for the upgraded third generation ATC system scheduled for implementation in the 1980's stress increased automation, two way data-link, traffic flow control, area navigation and microwave landing systems. At the same time, aircraft in service on international routes or operating out of the smaller domestic airports must have avionics equipment compatible with less advanced ATC systems. Thus, airborne avionics will continue to increase in functional capability as improvements are sought in all-weather capability, flight path separation, etc. Ultimate goals are greater aircraft safety, reductions in terminal area congestion, and improvements in equipment reliability and aircraft operating cost.

In the following pages an attempt is made to indicate the probable course of future avionics requirements for several classes of transport aircraft. These requirements will vary according to the operating environment of the aircraft. The avionics complement will differ between aircraft used in intercontinental or domestic travel, long haul or short haul, and between aircraft operating at high or low traffic density terminals. Differences are primarily in communication and navigation equipment. For example, long range aircraft used on transoceanic flight generally have inertial navigation and/or Doppler navigation as a primary navigation system. Over land these systems are considered useful for supporting VOR/ILS and DME equipment, but are not required.

Short Haul

Aircraft used for short haul transportation may be in service at both major airports and at the smaller airports serving communities with low population densities. Thus, these aircraft will often land at airports unequipped to handle landings in low visibility, low ceiling, crosswinds, storm activity and poor runway taxi conditions. However, the aircraft must also be able to land at hub airports equipped to handle these weather conditions. Therefore, many of these aircraft will carry equipment for Category II and eventually Category III weather operation.

Representative avionics requirements for short haul missions in 1980, between low density terminal area are indicated in figure 5. Two columns of equipment weight and cost are shown. The lower values represent the minimum acceptable expenditure, while the higher values indicate the more likely complement for commuter aircraft.

STOL

For STOL aircraft whose landing speeds are less than CTOL, the effects of wind shear, gusts, and crosswinds will become more pronounced in the final approach and landing phase than for conventional aircraft. Since much of the STOL aircraft's lift is propulsive, management of engines becomes primary in the approach phase and engine controls and displays will need to be prominent and possibly integrated with flight director displays.

Equipment ⁽¹⁾	Minimal		Nominal	
	Wt ⁽²⁾	Cost ⁽³⁾	Wt ⁽²⁾	Cost ⁽³⁾
VHF Comm (2)	29.0	6,843	45.0	9,560
Audio Control (2)	6.0	405	9.0	1,764
ATC Transponder (2)	14.8	3,375	32.6	10,360
Audio System				
Flight Interphone Sys.	30.0	3,300	44.0	4,764
Service Interphone Sys.				
Passenger Address Sys.				
Passenger Call Sys.				
Voice Recorder	15.0	2,300	19.7	2,708
Flight Recorder	30.0	7,500	40.0	10,000
Tape Reproducuer	7.0	3,800	10.0	5,000
ADF (2)	26.6	4,875	54.0	12,042
VOR/LOC (2)	12.6	2,880	81.6	14,116
GS (2)	3.3	750		
Marker Beacon	4.3	1,099		
DME (2)	34.4	7,493	51.6	22,978
Radio Altimeter (2)	13.8	7,329	53.0	17,324
Attitude Reference (Vertical gyros)(2)	12.0	12,300	30.4	6,000
Heading Reference (Directional gyros)(2)			43.4	15,000
Weather Radar	45.0	12,075	62.9	14,328
Autopilot (AP)	24.4	7,650	34.0	11,580
Flight Director (FD) (2)	64.2	30,878	35.2	28,550
Auto Throttle (AT)	NA	NA	30.7	14,000
Instrument Failure Warning Sys.	17.3	3,646		
Attitude Director Indicator (ADI)	9.0	7,200	19.0	13,200
Horizontal Situation Indicator (HSI)	Incl. in FD	Incl. in FD	17.0	15,200
Radio Magnetic Indicator (RMI)(2)	8.0	6,800	16.0	2,400
Air Data Computer (DADS)	Incl. in FD	Incl. in FD	25.0	14,000
Area NAV Computer (RNAV)			40.00	67,000
Total	406.7	132,498	799.4	313,286

(1) Except for the integrated displays listed individually (ADI, HSI, RMI), equipment listed includes associated control panel, indicator, and antennas

(2) Weight is uninstalled (add approximately 10% for installation)

(3) Cost is net, uninstalled 1972 dollars.

Figure 5.— 1980 Avionics Requirement for Low Density Short Haul Aircraft

The Ames Research Center is involved in an experimental STOL avionics system called STOLAND. Sperry Rand Flight Systems Division under contract to NASA will deliver three systems; the first is currently installed on a flight simulator for evaluation. The STOLAND system uses a single, general-purpose digital computer for all navigation, guidance, control, and display information. The general-purpose computer is integrated with flexible pilot controls and with both electromechanical and cathode-ray-tube displays. Several hundred hours of flight tests of six STOLAND configurations will be used to help determine the Category I, II, and III requirements for STOL aircraft.

Long Haul

The Boeing Company, under contract to NASA, has investigated advanced subsonic transport designed for terminal area compatibility. Preliminary data (ref. 46) have defined a terminal configured vehicle (TCV) avionics requirement divided into two categories: (1) those due to the electronic interface with navigation, communication, and surveillance equipment external to the airplane; and, (2) those due to airplane performance capabilities necessary to operate within the ATC system. These are summarized in figure 6.

The avionics requirements are based on the DOT/FAA National Aviation System Ten Year Plan (ref. 47) and the Boeing Fourth Generation ATC System concept (ref. 48). Isolated electronic equipment such as the passenger entertainment system are not included. The avionics system has Category IIIa landing capability which includes fail-operational automatic landing sensors, computers, and actuators; some guidance during initial landing roll; and a monitor system. The system monitor computer accepts input from digital acquisition units for maintenance monitoring of such systems as engines, electrical, and hydraulic; and, ties directly to the digital data link to transmit both airline and ATC information over a single data link. A separate system, called a Landing Monitor (LM), independent of the basic automatic landing system, will be necessary. The LM employs external sensors, integrates these with the basic monitor system to determine that the avionics system is operating correctly, and displays an indication of this.

Type	Equipment	Redundancy
Communication	Satellite L-Band Digital Data Link Satellite L-Band Voice Comm. ATC Coded Transmitter	
Navigation	Strapdown Inertial Sensor System (ISS) Central Avionics Computers for RNAV System Monitor Computer Landing Monitor Microwave Landing System (MLS) Receivers VLF Navigation Receiver (probably OMEGA)	4 2
Flight Control	Stability Augmentation System (SAS) AFCS (for Cat. III automatic landing)	4 3
Instrumentation	CRT Displays Electronic Attitude Director Ind. (EADI) Pictorial Navigation Display (PND) Multifunction Display (MFD) Digital Acquisition Units (Engines, Elec., etc.)	

Figure 6.— Subsonic Transport Avionics Requirements 1985—2000

Supersonic Transport

The supersonic transport (SST) has substituted augmented aircraft stability for inherent stability. This requires a control system that provides acceptable flying qualities in all-weather operation, and provides sufficient reliability to insure safety and to meet the demanding airline operational environment. The U.S. SST program had completed several design cycles on an analog quadruple-redundant primary FCS and the stability augmentation systems (ref. 49). Some of this work is being continued by the Boeing Company under contract to the DOT (Contract DOT-FA-SS-71-12). In particular, effort is being directed toward determining the applicability of digital computation techniques to flight critical control applications. Other avionics related technology study areas which have been identified by The Boeing Company under contract to NASA (ref. 49) as important items for an SST program include: (1) an angle-of-attack warning and limiting system, (2) advanced digital systems development, (3) power-by-wire FCS, (4) advanced indirect cockpit vision technology, (5) flight deck display, (6) radio frequency systems, (7) weather radar, and (8) on-board weight and C.G. measuring and indicating system.

The Concorde will have an integrated AP/FD system which has two pitch and two azimuth computers (ref. 50). The autothrottle system and the electric trim system will each have two self-monitored computers. A digital processor will provide all warnings associated with the AFCS by systematically interrogating built-in test equipment (BITE). The AP/FD computer is essentially analog so it will be necessary to have analog-to-digital conversion equipment to interface with the processor casting approximately 10-15% in the MTBF of each unit. The AFCS computers will be an open layout design rather than throw-away functional modules because of the expense involved in maintaining a large inventory of specialized modules.

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